STEAM AND HOT WATER HEATING

A. M. DANIELS

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STEAM AND HOT WATER HEATING

BY

ARA MARCUS DANIELS

Consulting and Advisory Engineer

WASHINGTON, D. C.

SPECIALLY ARRANGED
FOR
HOME STUDY

AUTHOR OF

Warm Air Furnace Heating, U. S. Government Bulletins,
Operating a Home Heating Plant, One-Register Furnaces,
Chimneys and Fireplaces

CONTRIBUTOR TO

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The Heating and Ventilating Magazine
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Domestic Engineering

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PREFACE TO FIRST EDITION.

Heating is fast being recognized as a science. Investigational work accomplished and in progress by varied research bodies executing independent programs or working on co-operative projects speaks well for the future for the heating professions.

Surveys of conditions in different cities have indicated the lack of full appreciation of the economics of properly designed and installed plants. With from 50 to 85 per cent of residences in certain centers of population equipped with inadequate, inefficient and uneconomical heating plants, much educational work is necessary before there will be a wholesome respect for this industry.

It is hoped that this book may serve as a working tool for those responsible for correct heating installations and lend its aid in assuring a deeper appreciation in the minds of those responsible for the actual installation, for, not only the need of a better understanding of the fundamentals of the science of steam and hot water heating, but that it may serve also to stress the obligation imposed upon those who would sell and install such systems with justice to themselves and the users.

In the presentation of this book, the author has digressed somewhat from the accepted standard, in order that the material may better suit the requirements of the student without in any way making it less valuable as a reference work for the craftsman.

This treatise is primarily a home study course in gravity steam and hot water heating. The entire book is arranged in a sequential order commencing with simple fundamentals and proceeding by a logical step-by-step method, so developed that one having no knowledge of the subjects may study with ease.

The work in its original form has been used for several years as the text of a course of instruction by mail. The demand for the material in book form as a reference work has prompted this publication.

Throughout the text there appear references as Work Problem No. ——. These designate the points throughout the text where the student of the course by mail was assigned a certain problem to exemplify the principle covered in the paragraph preceding.

To him who elects to use this book as the means for acquiring a working and practical knowledge of steam and hot water heating, the following instructions should be observed: (1) Do not read it helter-skelter like but *commence at the beginning* and be sure that the contents of every paragraph are *thoroughly* understood before taking up a subsequent one; (2) Do not be over anxious to complete the study quickly; (3) Assure oneself that the principles and their application covered in the first subdivision of the book are fully understood before proceeding to study the second part and so on.

For him who desires to use the book as a reference work, a complete index by page numbers is included at the back.

Should this book succeed in arousing sympathetic interest toward a full appreciation of the importance of proper design and installation, and assist in some small way toward this end, the author will feel justified in its publication.

Detection of errors and constructive criticisms that readers may have to offer will be welcomed that together we may labor in the cause of improved heating service.

A. M. DANIELS.

Washington, D. C.,
October, 1928.

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PART 1.

FUNDAMENTALS OF HEATING

LESSON 1.

Basic Data

BASIC HEATING AND VENTILATING DATA.

In commencing the study of Heating and Ventilating Engineering, it is absolutely necessary that we first become familiar with the media and terms with which we must deal. We have two natural substances, air and water, and one form of energy, heat.

SPECIFIC DENSITY—SPECIFIC VOLUME—SPECIFIC HEAT.

These are terms which we will use frequently. We should understand clearly what they mean. Specific density of a substance means the weight in pounds of a cubic foot of that substance.

Specific volume of a substance means the number of cubic feet in a pound of that substance.

Specific heat of a substance means the quantity of heat required to raise through 1° F. the temperature of 1 lb. of that substance under atmospheric pressure.

SPECIFIC DENSITY AND VOLUME OF AIR.

Tables often designated as "Properties of Air" are to be found in various "hand-books" and in such tables, one column invariably contains values for the specific density or weight of a cubic foot of air at different temperatures under atmospheric pressure. A comparison of such a column would show that the density changes as the temperature changes but not in the same manner. As a cubic foot of air becomes warmer, its weight becomes less.

Values for specific density and specific volume are not always given in the same table. It is frequently necessary to deduce the specific volume from the specific density. It is done by dividing (1) representing a cubic foot, by the specific density (number of pounds in 1 cu. ft.). So if the specific density of air at 30° F. is 0.08107 lbs., the specific volume will be $1 \div 0.08107 = 12.34$ cu. ft. per pound.

Work Problem No. 1

SPECIFIC DENSITY AND VOLUME OF WATER

Tables, similar to those for "Properties of Air" are also found in "hand-books" designated often as "Properties of Water." The weight of a cubic foot of water differs for different temperatures. This is due to the fact that as water is heated it becomes less dense and thus weighs less per cubic foot. Tables for "Properties of Water" contain a column showing the density or weight in pounds of a cubic foot of water for all temperatures between 32° and 212° F. The following are important temperature points:

Temperature Deg.	Condition	Weight pounds per cubic foot (Density)
32	Freezing Point	62.418
39.2	Maximum Density	62.427
62	Standard Weight	62.355
212	Boiling Point	59.760

It is advisable for the student to familiarize himself with such tables for air and water.

Work Problem No. 2

A U. S. gallon of water which is equivalent to 231 cu. in. weighs approximately 8 1/3 lbs. at a temperature of 62° F. A cubic foot at this temperature contains 7.48 gal.

Work Problem No. 3

PRESSURES MEASURED BY WATER COLUMN

Pressures are often stated in "feet head" or "inches of water column" and it may be advisable to express such in terms of pounds per square inch. At a temperature of 62° F., a column of water 1 ft. high that covers an area of 1 sq. ft. would exert a pressure of 62.355 lbs. per square foot or $62.355 \div 144 = 0.433$ lbs. per square inch. So for a column 15 ft. high, the pressure at the base would be $15 \times 62.355 = 935$ lbs. per foot or $15 \times 0.433 = 6.52$ lbs. per square inch.

Work Problem No. 4

Pressures are also frequently given and recorded in ounces per square inch of water pressure. If the head or pressure in inches of water at a temperature of 62° F. be divided by 12 (inches per foot), this quotient multiplied by 62.355 (weight of 1 cu. ft. at 62° F.), this quotient divided by 144 (square inches per square foot) and the resulting product multiplied by 16 (ounces per pound), the result will be the pressure in ounces per square inch. Or, expressed so as to convert recorded pressure in ounces per square inch to equivalent head in inches of water: multiply the recorded pressure by 1.73 to obtain head in inches of water.

Work Problem No. 5

Specific volume of water as for air is obtained by dividing one (1) by its specific density at a given temperature.

Work Problem No. 6

It is often necessary to express a given volume of water at a known temperature as equivalent pounds. To do this a "Properties of Water" table is used. Selected values from such a table are given directly below.

Temperature Deg.	Weight per cubic foot, pounds
60	62.37
80	62.23
100	62.02
120	61.74
140	61.37
160	60.98

Suppose it is desired to know the weight in pounds of 5.47 cu. ft. of water at 80° F.

5.47 (cu. ft.) $\times$ 62.23 (lbs.) = 340.4 (appx.), total pounds.

Work Problem No. 7

TEMPERATURE AT WHICH WATER BOILS

Water boils at different temperatures. The boiling temperature depends upon the pressure. At sea level, atmospheric pressure is equal to 14.7 lbs. (appx.) per square inch. The boiling temperature at this pressure is 212° F. On the top of a mountain 10,685 ft. above sea level, atmospheric pressure is equal to 9.74 lbs. per square inch, due to the decreased density of the air. Under this pressure pure water would boil at 192° F. So by reducing the pressure, the boiling point of water may be lowered. This is an important fact and should be remembered as we will have frequent occasion to apply the principle as we progress in our study of the application of fundamental principles.

WHAT IS A HEAT UNIT?

No part of our preliminary preparations is near so important as that we should understand perfectly the term, B.T.U. It stands for a unit of heat.

If the bulb of a thermometer is immersed in a pail of water, the height of the mercury column will

indicate the temperature of the water. But the quantity of heat in the water will not be known. The temperature, however, may be a means by which the quantity of heat may be determined.

If 1 lb. of water at 62° F. be raised to 63° F. at atmospheric pressure, a definite quantity of heat will have been imparted to the water. Careful experiments have shown that for a degree rise at any point between 32° and 212° F. the quantity of heat imparted differs. In other words, the quantity of heat required to raise a mass of water 1° F. is not a constant quantity throughout the thermometric scale. It is so nearly constant though, that it is common practice to define a B.T.U. as the 1/180 part of the heat required to raise 1 lb. of water from 32° to 212° F., or through 180° F.; or as the heat required to raise the temperature of 1 lb. of water 1 degree. So the quantity of heat required to raise a given quantity of water at a definite temperature to a desired temperature may be found by multiplying the weight of water in pounds by the temperature difference in degrees. Thus, 125 lbs. of water at 40° F., if raised to 190° F., will require 125 (lbs.) $\times$ (190-40) = 18,750 B.T.U.

Work Problem No. 8

SPECIFIC HEAT

Specific heat is a term used frequently in heating calculations. It has been defined (for a given substance) as the ratio of the heat required to raise the temperature of the unit weight of that substance 1° F. and the quantity of heat required to raise the temperature of the same weight of water 1° F., usually from 62° to 63°. Some engineers contend that a more correct name for the quantity is "coefficient of thermal capacity."

Applied to water, specific heat means the number of units of heat required to raise 1 lb. (the unit weight of water) through one unit of temperature. As explained above, the quantity varies slightly with the temperature but the difference is so little that the specific heat or "coefficient of thermal capacity" of water is quite commonly taken as unity and so

used in most heating calculations. Values at each of five different temperatures are given below as evidence of the very slight difference.

Temperature, Deg. F.	Specific Heat
30	1.0098
55	1.0000
100	0.9967
160	1.0002
210	1.0050

Applied to air, specific heat has quite a different value than for water. Suppose the B.T.U. required to raise the temperature of 1 lb. of water from 62° to 63° F. is called A, B.T.U. and that the quantity of heat required to raise the temperature of 1 lb. of air 1° from any temperature between, say, 22° F. below zero to 200° F. above zero and under the same conditions of pressure as for the water, is measured and called B, B.T.U. If the B quantity be divided by the A quantity, a value that represents the relation that exists between these two heat quantities will be obtained.

Suppose the value of the A quantity were twice as large as the B quantity. The relation number would then be 0.50, which would indicate that for a given quantity of air just one-half as much heat would be required to raise its temperature a definite number of degrees as would be required to raise the temperature of an equal amount of water through the same number of degrees. This relation, expressed as a decimal, is what is known as the specific heat or coefficient of thermal capacity of the substance.

For air, under conditions of constant pressure and within practical working temperatures, it is taken as 0.24 B.T.U. per pound. In other words, practically, it requires but 24/100 as much heat to raise the temperature of 1 lb. of air 1° F. as it does to raise 1 lb. of water 1° F.

So the quantity of heat required to raise the temperature of a given quantity of air at a definite temperature to some desired temperature may be found by multiplying the weight of air in pounds by the temperature difference in degrees and this product by the coefficient of thermal capacity. Thus 125 lbs. of air at a temperature of 40° F., if raised to a

temperature of 190° F. will require 125 (lbs.) × (190-40) × 0.24 (coef.) = 4,500 B.T.U.

The value for the specific heat of air, as determined by various investigations varies from 0.2375 to 0.2430. The value commonly used is 0.24.

Work Problem No. 9

LATENT HEAT OF EVAPORATION

This is a term commonly heard and frequently used in connection with heating calculations, especially in steam work. When heat in sufficient quantity is added to water, the water is changed from the liquid to the gaseous state which is steam. It will remain steam just so long as the quantity of heat which was required to change it from a liquid into a gas remains in it. This quantity of heat is known as the Latent Heat of Evaporation.

When the application of heat results in a change of state of a substance, either from solid to liquid or from liquid to gaseous, there occurs an absorption of heat without rise in temperature and the heat thus absorbed is termed LATENT (or hidden), because it apparently disappears, and may not be measured with a thermometer. It is not lost, however, but re-appears whenever the substance passes through the reverse cycle, that is, from a gaseous to a liquid or from a liquid to a solid state. LATENT HEAT is, therefore, the quantity of heat which apparently disappears, or is lost to thermometric measurement, when the molecular constitution of a body is being changed. It is expended in performing the work of overcoming the molecular cohesion of the particles of the substance, and in overcoming the resistance of external pressure to change of volume of the heated body.

LATENT HEAT AS APPLIED TO WATER

To understand this perhaps better, consider a pound of water in the three states, solid (as ice) liquid (as water) and gaseous (as steam). If heat be applied to a pound of ice at some temperature below 32° F., there will be a rise in temperature until 32° F., the freezing point, is reached. The ice

will then begin to melt, but the temperature of the mixture of ice and water will remain 32° F. as long as any particle of ice remains in it.

Yet the melting process will absorb heat, NOTE THAT. This amount of heat thus absorbed in changing the state of a pound of ice from ice at 32° F. to water at 32° F. is 144 B.T.U. It is called the LATENT HEAT OF FUSION of ice.

Now if the application of heat be continued, the temperature of the water (after all the ice is melted) will rise, but about twice as many units (the ratio of 0.463 specific heat of ice to 1, the specific heat of water) as before, will be required to raise it 1° F. When the temperature of the water has reached 212° F., there begins a further absorption of heat but no increase in temperature. Boiling occurs, and the absorbed heat is expended in transforming the water into steam. Water at atmospheric pressure cannot be heated above 212° F. When the entire pound of water has been changed or evaporated into steam, 970.4 B.T.U. will have been added. This is the LATENT HEAT OF EVAPORATION of water.

Work Problem No. 10

OPERATIONS REQUIRED TO WARM A ROOM.

There are three general operations performed during the process of warming a room. First, fuel is burned. This may occur in a fireplace, stove, furnace or in a steam or hot water boiler. Second, the heat generated by the combustion of the fuel is conveyed to the room to be heated. Third, the heat conveyed to the room is diffused to the air therein, to the walls, floor and other parts.

Work Problem No. 11

SYSTEMS OF HEATING.

Means by which rooms may be heated may be mentioned as follows: 1. Stoves, 2. Furnaces, pipe and pipeless, 3. Direct Steam, 4. Indirect Steam, 5. Direct-Indirect, 6. Direct Hot Water, 7. Indirect Hot Water, 8. Exhaust Steam, 9. Forced Blast, 10. Electricity.

STOVES.

This is the simplest and cheapest form of heating. The heat from the combustion of the fuel is radiated and conveyed directly to the air and objects of the room. No special system of conveyance is employed.

FURNACES.

The term "furnace" usually refers to the warm-air heater. In this method of heating, air is drawn over the heated surfaces of the furnace and flows through large galvanized iron or tin pipes at a comparatively high temperature, to the rooms which are to be heated.

DIRECT STEAM.

This system is applied to all classes of structures. It is used separately and in combination with other systems. It is frequently necessary to supplement it with some form of ventilating system. In this method of heating, the steam generated in the boiler passes through pipes to radiators located in the room to be heated. As the steam in the radiators condenses, it gives up part of its heat to the walls of the radiator from which it is dissipated throughout the room. The water of condensation flows back to the boiler to be again converted into steam and the cycle repeated.

INDIRECT STEAM.

In this system of heating, instead of placing the radiators in the rooms, a special form of heater is supported near the basement ceiling and encased in either galvanized iron or brick. A cold air duct is connected with the space below the heater, and warm air pipes are taken from the top and connected with registers in the rooms to be heated similar to furnace heating. A separate stack or heater may be provided for each register if the rooms are large but if small and so located that they may be reached by short runs of horizontal pipe, a single heater may serve two or more rooms.

DIRECT-INDIRECT.

This system calls for the use of direct-indirect hot water or steam radiators and provides for the

circulation of either inside or outside air through a radiator of the FLUE TYPE. It is placed directly in the room to be heated. They are connected to the outside air by a suitable cold air duct usually run in the outside wall.

DIRECT HOT WATER.

This system is similar in operation to the direct steam system. Water, instead of steam, is used in the radiators. The water is heated in the hot water boiler which is usually located in the basement. All pipes and radiators are filled with water which circulates to and from the radiators due to the difference in density of the water in the flow and return sides of the system. As the water in the radiator is cooled by imparting some of its heat to the walls thereof, it falls to the bottom of the radiator and thence into the return piping, the heat being diffused to the room as in the case of the direct steam radiator.

INDIRECT HOT WATER.

This system is similar to indirect steam. Water, instead of steam, being the heating medium.

EXHAUST STEAM.

The exhaust steam system of heating is used in connection with power plants, as in shops and factories, or in office buildings that have their own lighting plants. Two methods by which this system is used are practiced, namely, (a) under a slight pressure (2 to 5 pounds) and (b) by using some form of vacuum system which tends to reduce the pressure within certain limits. The steam used is that which has been through the engines and therefore has become reduced in pressure but still contains heat units which may be utilized for heating.

FORCED BLAST.

This method of heating, in different forms, is used for the warming of factories, schools, churches, theatres, halls and in fact any large building where good ventilation is required. The air for warming is drawn or forced through a

heater of special design and discharged by a fan or blower into ducts which lead to registers placed in the rooms to be warmed.

ELECTRIC HEATING.

The resistance offered by a wire to the passage of electricity through it manifests itself in the form of heat. Therefore, to heat with electricity the heater is placed in the room to be heated and direct radiation results. This is not applicable to the heating of residences or large buildings unless the current is obtainable at a comparatively low cost.

Work Problem No. 12

PRINCIPLES OF VENTILATION

The problem of maintaining air in various buildings at a certain standard of purity is intimately connected with the subject of heating. In order to properly understand some of the reasons underlying the necessity of supplying fresh air, a few paragraphs are to be devoted to this subject. All too frequently the subject of ventilation receives very little consideration in connection with the erection of apparatus for heating.

OXYGEN.

As related to heating and ventilating, oxygen is one of the most important elements of the atmosphere. When fuel is burned, oxygen is the active element in the process. A somewhat similar physiological process takes place in the respiration of human beings. Oxygen is absolutely essential for the support of life. It should not be considered as having any properties as a food, but is rather the necessary element which makes it possible to assimilate and utilize the food.

With every breath, it is taken into the lungs. It acts upon the excess of carbon of the blood, and possibly also upon other ingredients, forming chemical compounds which are thrown off in the act of respiration. Generally, the action of oxygen with the other elements can be considered as sanitary. Respiration, in many respects, resembles that of combustion. The process in both cases is: Oxygen is derived from the air, carbon or other

impurities are oxidized, and the products of this oxidation are rejected. IN BOTH CASES HEAT IS GENERATED.

Work Problem No. 13

ACTION OF OXYGEN WITH CARBON.

When oxygen and carbon combine, and this happens when combustion occurs, CARBONIC OXIDE OR CARBON DIOXIDE may be formed. If the combustion is perfect, that is, if all the oxygen that the carbon is capable of uniting with is utilized then CARBON DIOXIDE or CARBONIC ACID is formed. This product is always present in the atmosphere but in the country, that is, in fresh or pure air it occurs in small quantities, 3 to 5 parts in 10,000 parts. Carbonic acid gas is very much heavier than pure air but it will mix uniformly with it if given sufficient time.

Carbonic acid gas or carbon dioxide in itself is not dangerous to health, but when carbon dioxide is exhaled, other gases that are harmful are given off at the same time and it is these that may prove a menace to health. The carbon dioxide serves more or less as an indicator of the presence of the real danger. If carbon dioxide is present in the air in considerable quantity, dullness, headaches, and fainting are liable.

Work Problem No. 14

CARBONIC ACID GAS AS AN INDEX OF THE QUALITY OF THE AIR.

Carbonic acid gas being a product of combustion and respiration and usually accompanied by other injurious products, may, therefore, be regarded as an index of the quality of the air and the amount of it present in the air is taken as the standard by which the efficacy of the ventilation may be judged. Authorities differ as to the greatest amount of carbon dioxide which might be permitted. It is seldom that the occupants of a room experience any unpleasant sensation until the amount of carbon dioxide reaches to 10 or 12 parts in 10,000. Yet authorities are generally agreed that the maximum amount should not exceed 10 parts in 10,000. At present, the standard of good

ventilation usually adopted permits of about 8 parts in 10,000 in the air.

Work Problem No. 15

CARBONIC OXIDE.

This compound is commonly spoken of as carbon monoxide and its effects upon the human system are pretty well appreciated.

It is a poisonous gas and a few years ago deaths from it were of rather frequent occurrence. It is the direct result of incomplete combustion and special care should be exercised in closed rooms where this is liable to occur such as closed kitchens with gas heaters or garages with poor ventilation.

Work Problem No. 16

HUMIDITY—WATER VAPOR IN AIR.

A certain amount of moisture or water vapor is almost always present in the atmosphere. The greatest amount of vapor that may exist in the air depends upon the temperature and varies from 0.00007 lb. per cu. ft. at 0° F. to 0.00282 lb. per cu. ft. at 100° F. Rainfall is controlled by the degree of saturation of the air and health is also influenced.

Humidity is the water vapor or moisture mixed with the air in the atmosphere. The weight of water vapor a given SPACE will hold depends entirely upon the temperature and pressure. It is entirely independent of the presence or absence of air.

Work Problem No. 17

ABSOLUTE HUMIDITY.

This is the weight of a cubic foot of water vapor at a given temperature and percentage of saturation. It is usually expressed as grains per cubic foot.

RELATIVE HUMIDITY.

The moisture-carrying capacity of air depends on its temperature. Warm air has a much greater capacity for moisture than cold air, although it

may feel drier. It is the relation between the actual amount of moisture in the air at a given temperature and the amount of moisture that the air could hold at that temperature that causes it to feel dry or moist.

Consider a piece of cloth held in a vertical position and sprinkled with water. No water will drip from the cloth until it is completely saturated, holding all the water that it is capable of holding. So it is with air. When the air is so laden with moisture that water is deposited in the form of dew the air has reached the point of complete saturation, known as the dew point. Then the relative humidity is 100 per cent. If air contains seven-tenths as much water as is present when it has just reached the dew point, its relative humidity is 70 per cent. If a room having a temperature of 40° with air at 70 per cent relative humidity be warmed up to 70°, the percentage of saturation decreases with the increase of temperature, since the warmer the air the more moisture it is capable of holding in suspension. Unless more moisture is added as the temperature is increased the percentage of saturation will be reduced, so that whereas the air at the lower temperature held seven-tenths as much as it was capable of holding, under the higher temperature it holds only two-tenths as much. Then its relative humidity would be 20 per cent.

Thus, relative humidity is the ratio of the weight of water vapor in a given space to the weight which the space will hold when fully saturated at the same temperature, and is expressed as a percentage. The term "Humidity" as usually employed signifies relative humidity.

DEW POINT.

This is the temperature at which saturation occurs for a given weight of water vapor. It is the temperature at which any reduction in temperature would cause condensation of some of the water vapor as dew particles. Air containing any amount must have a dew point, since the temperature can be lowered enough to cause condensation.

Work Problem No. 18

INFLUENCE OF WATER VAPOR UPON VENTILATION.

The degree of moisture in the air has an impor-

tant influence on ventilation. If air is saturated with moisture, water is deposited on all bodies which conduct heat readily and have a lower temperature than the air. If the air, however, is entirely deprived of watery vapor, it will evaporate moisture from the body causing an unpleasant sensation. When fully saturated no evaporation can take place from the body. When very dry, very rapid evaporation will take place. Therefore, an average or mean condition is that which is desired. The best conditions of temperature and moisture for health have not as yet been definitely established. It is not unlikely that varying degrees of each, somewhat approximating outdoor conditions will be found best. At present some authorities state that a temperature of 68° F. with relative humidity between 40 and 50 per cent is believed best.

Work Problem No. 19

HEATING REQUIREMENTS

The quantity of heat required to maintain a desired temperature within a building or part thereof depends primarily upon two conditions:

(a) the purpose for which the building or part thereof is to be used,

(b) the outside temperature conditions which are likely to prevail in the locality.

The amount of heat which must be supplied hourly is governed by,

(1) the quantity that passes to the outside through walls, windows, doors, ceilings, roof and floors,

(2) the quantity required to raise the temperature of the outside air which enters either by leakage or is introduced for ventilating purposes, to the temperature to be maintained within,

(3) the quantity supplied by persons, lights, machinery, or other sources of heat generation within the building or part thereof.

Heat may be transmitted from a body (such as a water and steam radiator) or "lost" from a building or part thereof by Radiation, Conduction and Convection.

Radiant heat is transmitted from all bodies, the net amount of heat radiated from a body being the difference between the total amount radiated from it and the quantity radiated from other bodies that is absorbed by the body itself. Radiant heat follows certain definite physical laws, the principal one being stated as *The Intensity of Radiant Heat is Inversely Proportional to the Square of the Distance from the Source.* So, if a body is radiating 1,600,000 B.T.U., at a distance of 4 ft. the intensity of heat radiated will be equal to the quotient of 1,600,000 divided by 4^2, or 100,000 B.T.U.

Work Problem No. 20

Conducted heat is heat that passes from one part of a body or substance (or from one substance to another when the two are in direct contact) at one temperature to another part of the body at a lower temperature. Thus a flow of heat occurs through a body such as a brick wall when one side is warm and the other side comparatively cool. Different materials of which walls, floors, ceilings, roofs of structures are constructed conduct heat to a less or greater extent. Metals are better conductors than other materials so there will be a greater quantity of heat conducted through a metal roof in a given time than if the roof were built of some other material unless means for insulating it exist. Wood, felt, asbestos, etc. are examples of poor conductors.

The transmission of heat from a body by convection results when the warm or hot body is in contact with a fluid at a lower temperature, as with air in contact with a water or steam radiator or water surrounding a steam-filled pipe. The envelope of fluid surrounding the body becomes heated by conduction of heat from the body. As this part of the fluid is heated, it rises (due to the decrease in density) and is replaced by another layer of the fluid from below which in turn rises and thus a continuous current is created and maintained over the surface of the hot body. The heat thus carried away or conveyed is in turn given off to some colder body with which the fluid comes in contact, its density again increased, and it returns to the hot body to complete the cycle of operation. The essen-

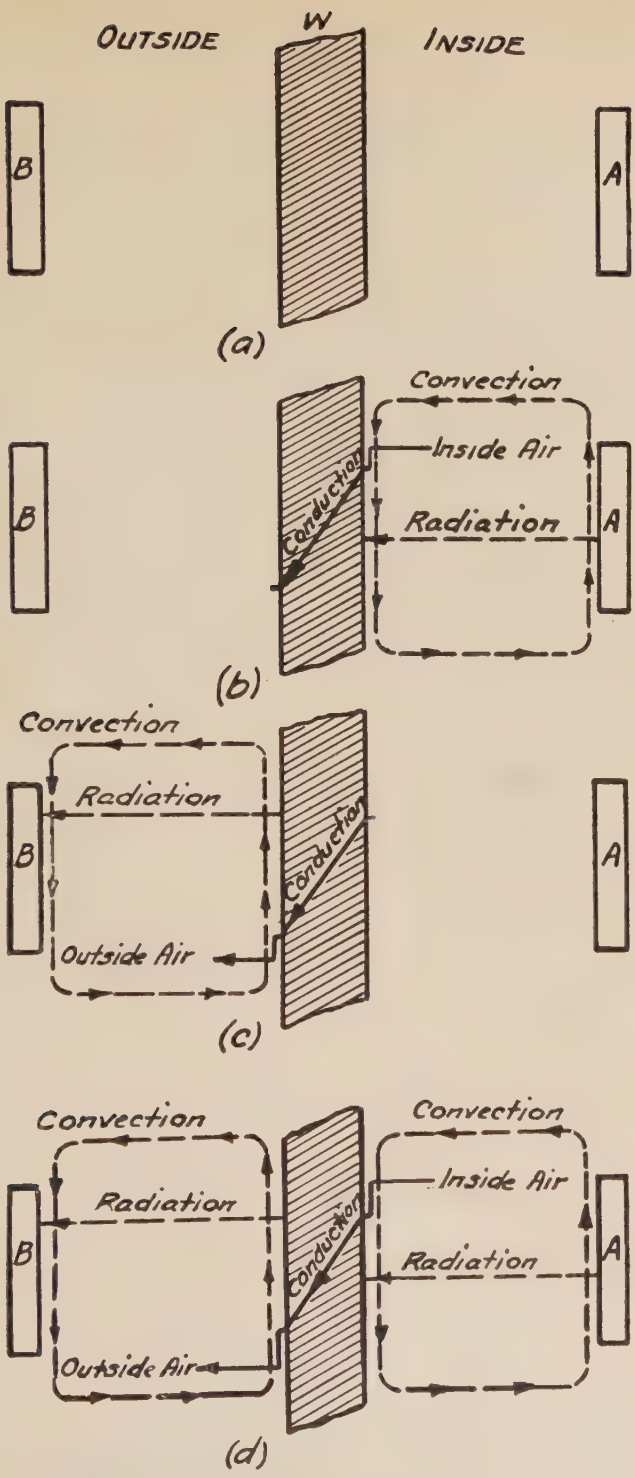

Fig. 1. –How Heat is Transmitted from and to Objects on Two Sides of a Homogeneous Wall.

tial characteristic of the process of convection is a continuous renewal of the fluid layer at the surface of contact.

TRANSFER OF HEAT

The manner in which heat is transmitted from and to objects on two sides of a homogeneous wall is shown graphically in Fig. 1. At (a), two objects, A and B are shown on opposite sides of the wall. If A has a higher temperature than B, heat will be transmitted from A to the wall by radiation, conduction and convection, as indicated at (b).

An infinite number of heat rays will radiate from A through the air without appreciably heating it, to the colder receiving surface or inside of the wall. The air in contact with A will become heated and rise, thus setting up a convection current as indicated and carry heat to the inner surface of the wall. Heat brought to the inside wall surface will be conducted through it as indicated by the heavy solid line drawn at an angle. The magnitude of the angle will depend upon the rate at which heat is conducted, the more nearly horizontal, the greater the conduction. Heat thus reaching the outer surface of the wall will be emitted in a reverse order to that received by the inner surface.

At (c) heat is shown radiating from the outside surface to B in straight lines, and carried by the convection current as indicated. Thus, as shown at (d), the transfer of heat will continue until the temperatures of A and B are equal.

In like manner heat is transmitted from a room to the outside but to a greater or less extent depending upon the type of construction. Factors, known as coefficients or multipliers and determined by experiments are applied when calculating the "heat loss" for a particular problem. These are known as coefficients, (1) of radiation, (2) of convection, and (3) of conduction.

COMBINED COEFFICIENTS OF RADIATION AND CONVECTION

Since, in experimental work it is difficult to separate the heat that is given off by a body by radiation

from that removed by convection, whereas the combined heat loss due to both radiation and convection in practically still-air tests may be obtained quite accurately, these two coefficients are usually applied as the combined effect and as such are frequently referred to as the surface coefficient.

The surface coefficient, therefore, means the B. T.U. absorbed or given off per square foot of surface per hour by radiation and convection (under definite conditions of air movements), per degree difference in temperature between the surface and the average temperature of the air. With different air movements on the two sides of a wall, the values of the surface coefficients will differ since the "heat loss" by convection will differ.

Coefficients derived from tests conducted under practically still-air conditions (the only movement being that caused by natural currents existing in the test room) are given in Table 1.

TABLE 1

SURFACE COEFFICIENTS FOR INSIDE WALLS
(COMBINED RADIATION AND CONVECTION FOR STILL AIR)

BUILDING MATERIAL	COEFFICIENT. K_1
BRICKWORK	1.35 TO 1.40
CONCRETE	1.30
CORKBOARD	1.25
CEMENT, PLASTER FINISH	0.93
GLASS WINDOW	1.50
SHEET ASBESTOS	1.40
MAGNESIA BOARD	1.45
WOOD (FINISHED SURFACE)	1.40

(HARDING & WILLARD)

TABLE 2

MULTIPLIERS FOR OBTAINING SURFACE COEFFICIENTS, K_2 FOR OUTSIDE WALLS UNDER MOVING AIR CONDITIONS

WIND VELOCITY, MILES PER HOUR	MULTIPLIERS FOR K_1	
	BRICKWORK	WOOD
5	2.38	2.19
10	3.20	2.71
15	3.76	2.95
20	4.22	3.02

(HARDING & WILLARD)

Surface coefficients for outside walls for moving-air conditions will be governed by the nature of the outside surface and the velocity of air movement over it. A general rule adopted by some engineers is to consider the outside surface coefficient as equal to three times that for a corresponding inside sur-

face. This figure is based on the assumption that exposed walls of a building are seldom subjected to an average wind movement of more than 15 miles per hour in extremely cold weather.

More specific values for outside wall coefficients for brickwork and wood for known wind velocities may be obtained by applying the multipliers given in Table 2.

Work Problem No. 21

CONDUCTIVITY OF MATERIALS

The property of conducting heat is possessed by all materials. The factor which indicates the quantity of heat that a material having parallel surfaces will transmit through it when the surfaces are at different temperatures is called its conductivity. The amount of heat conducted varies directly as the difference in the temperatures of the surfaces

TABLE 3

CONDUCTIVITY COEFFICIENTS, C.

B.T.U. TRANSMITTED PER SQ. FT PER HR PER INCH THICKNESS PER DEGREE "F" DIFFERENCE IN TEMPERATURE OF THE TWO SURFACES. MATERIALS THOROUGHLY DRY. (HARDING & WILLARD)

	C
* BRICKWORK	4.00 - (5.00)
CONCRETE (STONE 1 2·4 MIX.)	8.30
WOOD (FIR) ⅞ INCH THICK	1.00
CORKBOARD INSULATION	0.32
CORRUGATED ASBESTOS	0.48
SHEET ASBESTOS	0.29
MAGNESIA BOARD	0.51
* RECOMMENDED THAT VALUE OF C=5 BE USED	

THE FOLLOWING FIGURES ARE THE CONDUCTIVENESS FOR THE THICKNESS STATED. (B.T.U. PER SQ. FT. PER HR. PER DEGREE DIFFERENCE IN TEMPERATURE OF THE TWO SURFACES.) (HARDING & WILLARD)

GLASS (0.085")	24.3
WINDOW (76.3% GLASS)	8.64
DOUBLE WINDOW WITH ½" AIR SPACE	1.04
2" HOLLOW TILE PLASTERED BOTH SIDES	0.99
4" " " " " "	0.61
6" " " " " "	0.46
2" " " " " " WITH READY PREPARED GRAVEL ROOFING APPLIED TO ONE SIDE ONLY.	0.47
CONCRETE (CINDER 1·2·4 MIX.) 1" THICK (NORTON)	2.35
SANDSTONE 1" THICK (POENSGEN)	9.00
PACKED GRANULATED CORK (6.25 LBS. PER CU. FT.)	0.33
PACKED MINERAL WOOL (16.3 LBS. PER CU. FT.)	0.33
MORTAR 1" THICK	8.00
SLAG ROOFING (3 PLY) ⅛" THICK	0.40

and inversely as the thickness. Thus great temperature differences mean rapid conduction while the thicker the material the less heat conducted.

COEFFICIENT OF CONDUCTIVITY, C

Coefficients of conductivity are determined through experiments. Those obtained by different investigators will likely differ slightly since different samples of the same kind of material may vary considerable in density and conductivity.

Table 3 contains conductivity coefficients for various building materials. The values in this table are given as B.T.U. per square foot of wall surface per hour per inch thickness per degree F. difference between the two surfaces, for thoroughly dry materials.

With these data, the heat transmitted by conduction per square foot per hour may be obtained by subtracting the outside wall temperature from the inside wall temperature and multiplying the difference by the coefficient of conductivity as taken from Table 3 and then dividing by the thickness of the material in inches.

Work Problem No. 22

The values given in Table 3 should not be confused with those used later, (called "heat loss" coefficients) for walls composed of several layers of different materials. These values together with the surface coefficients, Tables 1 and 2, are used to derive values for "heat loss" coefficients for composite wall construction.

CALCULATING HEAT TRANSMISSION COEFFICIENTS

Various tables containing values for different types of wall construction are available in handbooks but in order to assure uniformity in this course, such tables will be presented from time to time and the student will be expected to use the values contained therein.

In all engineering work, tables are to be found that shorten the processes involved but to use a table without having some idea of how the matter

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contained therein was developed is liable to lead to undesirable results. Consequently, we will consider the development of values for "heat loss" coefficients (which we will designate as f) and calculate values for several typical walls before presenting tables containing such values.

The fundamental of heat transfer is stated as follows: the quantity of heat received by the inside surface of a wall, the quantity conducted through the wall and the quantity given off by the outside wall surface are equal to one another.

Thus we have three equal quantities, the values for which may be obtained as follows:

(1) The quantity of heat transmitted per square foot per hour for a given difference in temperature will be equal to the total temperature difference in degrees between the inside air and outside air multiplied by a factor (which we will designate as f) which is equal to the heat transmitted through an actual wall per square foot per hour per degree difference in temperature of the air on the two sides.

(2) The quantity of heat received by the inside surface of the wall will be equal to the product of the inside surface coefficient K_1 (explained above) by the difference in temperature between the temperature of the inside air and inside wall.

(3) The quantity of heat given off by the outside wall surface will be equal to the product of coefficient K_2 (explained above) by the difference in temperature between the temperature of the outside wall and outside air.

(4) The quantity of heat conducted through the material will be the difference between the temperature of the inside wall surface and outside wall surface multiplied by coefficient C (explained above) and this product divided by the thickness of the material in inches.

From the equality relation between these quantities a value for factor f may be deduced for any wall if values of the coefficients K_1, K_2, and C and the thickness are known or assumed. The following form may be used.

First:—Divide the numeral 1 (one) by the value of K_1 (from Table 1) corresponding to the wall in question.

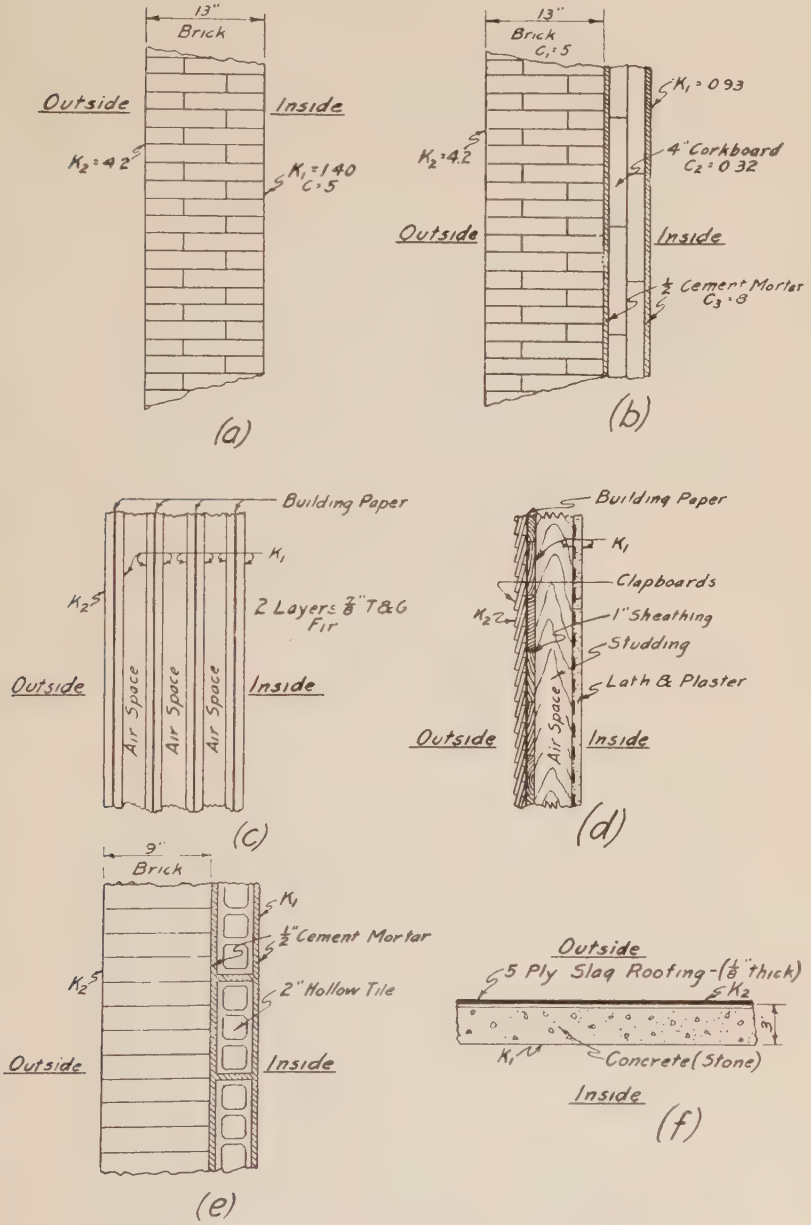


Fig. 2.---Examples of Composite Walls for Which Heat Loss Coefficients are Derived in Application Problems.

NOTE: For complete and original derivation, see page 58, Vol. I, "Heating and Ventilation, Mechanical Equipment of Buildings," by Harding and Willard.

Second:—Divide the numeral 1 (one) by the value of K_2 (as determined from Tables 1 and 2) corresponding to the proper wall.

Third:—Divide the thickness in inches by the value of C (from Table 3) for correct conditions.

Fourth:—Add results First, Second, Third.

Fifth—Divide numeral 1 (one) by result Fourth and obtain a value for factor f for the particular wall.

The value of f thus obtained may be used in making "heat loss" calculations for such a wall.

In Fig. 2 there are illustrated a 13-in. brick wall, four types of composite walls and one roof composed of the materials noted opposite each wall section.

It is desired to derive a value for f for the 13-in. brick wall shown at Fig. 2-(a). The values for the known factors are as follows:

$K_1 = 1.4$ (from Table 1).
$K_2 = 4.2$ (taken as $3 \times K_1$).
$C = 5$ (from table 3).
$T = 13$ in.

Applying the five-step form given directly above, a value of $f = 0.281$ is obtained.

Work Problem No. 23

CALCULATING COEFFICIENTS FOR COMPOSITE WALLS

Thus far we have considered only a wall composed of the same material throughout. If the wall consists of several different materials in direct contact with one another (no air spaces between), then to find a value for factor f we must proceed as follows:

First:—Divide the thickness of each different material in inches by the proper coefficient of conductivity and add the results obtained.

Second:—Divide numeral one (1) by the surface coefficient K_1 for the inside wall surface (from Table 1).

Third:—Divide numeral one (1) by the surface coefficient K_2 for the outside wall surface (as derived).

Fourth:—Add results First, Second and Third.

Fifth:—Divide numeral one (1) by results Fourth, and get a value for factor f.

The value for the thickness divided by coefficient

of conductivity for thin metal plates, building paper or glass is so small that it may be safely neglected in calculations.

In Fig. 2-(b) there is illustrated a composite wall consisting of two thicknesses of cement mortar, 4 in. of corkboard and 13-in. of brick. It is desired to derive a value for f for this wall. The values for the known factors are as follows:

$K_1 = 0.93$ (from Table 1).
K_2 = for brick wall = 4.2 (taken as $3 \times K_1$).
T for brick wall = 13 in.
T for corkboard = 4 in.
T for cement mortar = $2 \times \frac{1}{2}$ in. = 1 in.
C for brick wall = 5 (from Table 3).
C for corkboard = 0.32 (from Table 3).
C for cement mortar = 8 (from Table 3).

Applying the five-step form given directly above, a value of f = 0.053 is obtained as follows:
First: $(13 \div 5) + (4 \div 0.32) + (1 \div 8) = 15.225$
Second: $(1 \div 0.93) = 1.075$.
Third: $(1 \div 4.2) = 0.238$.
Fourth: $15.225 + 1.075 + 0.238 = 16.538$.
Fifth: $1 \div 16.058 = 0.060$.

Work Problems Nos. 24, 25, 26 and 27

APPLYING HEAT LOSS COEFFICIENTS, f

Knowing the heat loss coefficient, f, for a given wall construction, the transmission in B.T.U. per square foot of surface per hour can easily be obtained for any values for inside and outside temperatures by multiplying the temperature difference by the value f. In a foregoing paragraph for a 13-in. brick wall we determined a value f = 0.281.

Applying this for inside temperature of 70° F. and outside temperature of 0° F, the heat loss under these conditions will be $0.281 \times (70 - 0) = 19.7$ B.T.U. per square foot of surface per hour.

Work Problems Nos. 28, 29 and 30

PART 1.

FUNDAMENTALS OF HEATING

LESSON 2.

Heat Loss Coefficients

B.T.U. METHOD OF FIGURING HEAT LOSSES

Let us assume that the cross-hatched part of Fig. 3 represents a section of a hollow receptacle, cubical in shape. All six walls of this cube are assumed equally thick and impervious to heat, that is, regardless of how much or how little heat might be impounded within this hollow part, the walls are of such a character that none can escape. (This is a purely theoretical assumption since no material substance possesses this property.)

This hollow cube would then represent a container in which a quantity of heat might be retained indefinitely so that it would be necessary only once to supply the required number of heat units to assure maintaining the desired temperature within.

Practically, however since all substances permit heat to pass through them to a greater or less degree depending upon their density, thickness and the temperature existing on the two sides of the substance, it is necessary, in order to maintain a desired temperature within an enclosure continually to supply heat by an amount equal to that which the material permits to pass to the outside.

Referring again to Fig. 3, let us now assume that the cross-hatched part represents a room containing neither doors nor windows with inside length 10 ft., breadth 10 ft. and ceiling height above floor 10 ft. We will assume that each of the walls are built of brick, 12 inches thick, that the floor is constructed of 4 in. of concrete laid on the ground and that the ceiling is composed of lath and plaster.

We will now build around this imaginary room another enclosure such as is indicated by walls E and locate this outer enclosure so that the volume of the space L enclosed between these two hollow cubes will be equal to that contained within the smaller, noted as K. We will assume that the walls, bottom and top of the outer inclosure are impervious to the transfer of heat and that heat may pass through the walls, roof and ceiling of the inner room if conditions are favorable to such movement.

If we now introduce into space K just sufficient heat to establish a temperature of 100° F. in this inner space while a temperature of 0° F. exists in the space L, and then observe the result, we would find that heat would pass from the warmer to the cooler space with a consequent lowering of the temperature in K and a raising of the temperature in L, until these two temperatures are equal or reach 50° F.

The heat thus lost by space K and gained by space L passed through the walls, floor and ceiling of the inner room. This is exactly how heat is "lost" in the case of a residence, except that there is no outer wall impervious to heat transfer, as E, so that to maintain a desired temperature within a structure it is necessary to supply heat units continuously since those that pass to the outside are wholly insignificant so far as having any effect upon raising the outside temperature. To all practical purposes they represent "lost heat."

To determine the quantity of heat that must be continuously supplied for a particular case it is

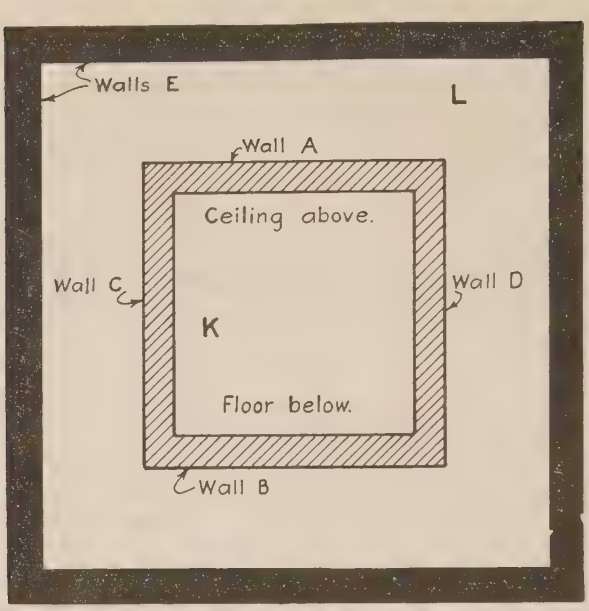


Fig. 3.—A Cubical Enclosure for Illustrating Heat Loss

necessary to consider the type of construction of which the walls, floors and ceiling are composed. This has a decided influence upon heat loss.

Experiments have been conducted to determine the quantity of heat that will pass through different types of walls, floors, roofs, ceilings, windows, doors and partitions, for 1° difference in temperature on the two sides of the wall. While different investigators have determined slightly different values, owing to minor variations in the compositions of materials or methods used, in general, results substantially agree.

For the purpose of uniformity in this course and to acquaint the student who is just entering the heating and ventilating profession with the use of such tables all necessary data of this kind are included and the student will be expected to use them in his solutions of the assigned problems. Tables 4 to 12 inclusive containing heat transmission values for various types of construction are presented with this lesson. The student should carefully study these tables and familiarize himself with their contents. Each table contains a description of a type of con-

struction, together with a value for that construction. This value under B.T.U. in each table expresses the quantity of heat that will be transmitted per degree difference in temperature per hour per square foot of surface.

Work Problem No. 31.

HEAT LOSS FROM WALL OF UNIFORM CONSTRUCTION

Let it be required to calculate the heat loss per hour from a plain brick wall 16 ft. long by 12 ft. high by 16 in. thick when the temperature on one side is maintained at 70° F. and on the other side at 0° F. Proceed as follows:

Area of wall = 16 ft. x 12 ft. =192 sq. ft.
Heat loss per hour per square foot per degree F. temperature difference (by Table 4) = 0.25 B.T.U.
Total temperature difference = 70°—0° = 70° F.
Total hourly heat loss = $192 \times 70 \times 0.25 = 3360$ B.T.U.

Work Problem No. 32.

EFFECT OF TYPE OF CONSTRUCTION ON HEAT LOSS

An approximate comparison of the effectiveness of different types of construction as regards heat loss therefrom may be obtained by comparing their transmission factors. Thus the heat loss through a frame wall built of clapboards on studs (see Table 5) as compared to a plain brick wall 12 in. thick (see Table 4) is as 0.62 is to 0.29, or the loss through the frame wall will be more than twice that through the brick wall. Therefore, more than twice as much heat would need to be supplied to a room built of clapboards on studs as if the walls were of plain brick 12 in. thick.

Work Probems Nos. 33 and 34.

The heating and ventilating engineer is usually called upon to prepare his design from submitted blue prints. It is necessary therefore to take dimensions from the blue print or to scale it. In Fig. 4 portions of two walls are shown for which the heat loss in B.T.U. are to be calculated.

Work Problems Nos. 35, 36 and 37.

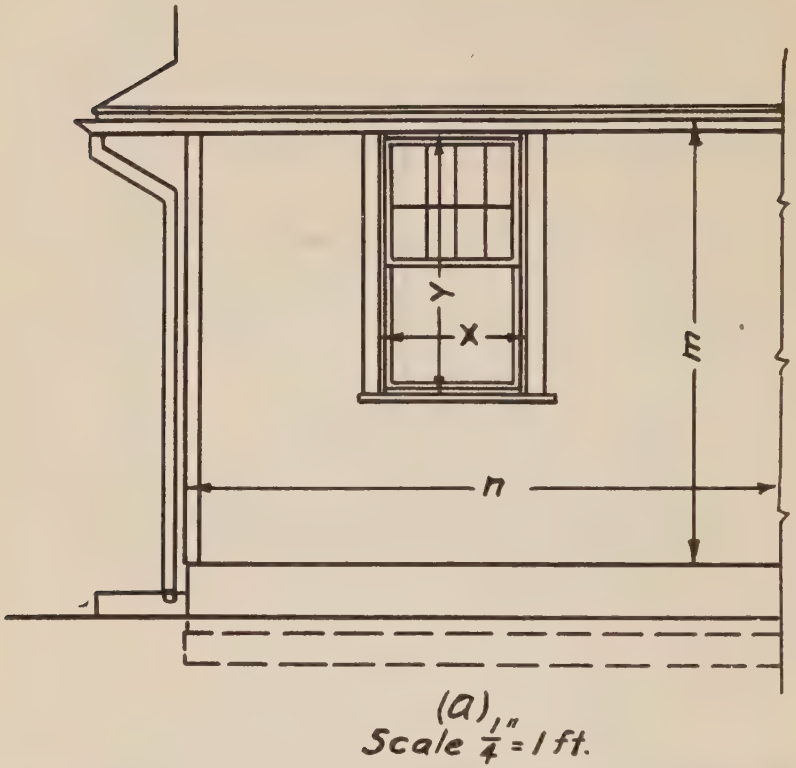


Fig. 4. Parts of Walls for Problems Relating to Heat Loss

HEAT LOSS FROM WALLS CONTAINING WINDOWS AND DOORS

Thus far we have considered walls of continuous construction to demonstrate heat loss principles involved. We will now consider walls which contain window and door openings and will see that such openings have a marked effect on the heat requirements of a given room.

In Fig 5 is illustrated a plan of a room having three outside windows and one outside door. The room is 14 ft. long, 10 ft. wide and has a ceiling height of 9 ft. The outside door is 3 ft. by 7 ft. and each of the windows is 2 ft. wide x 4 ft. 6 in. high. We desire to know how many heat units will be required to maintain a temperature of 70° F. within space K when the outside temperature is 0° F. It will be assumed that inside spaces M and N adjoining K, are to be maintained at the same

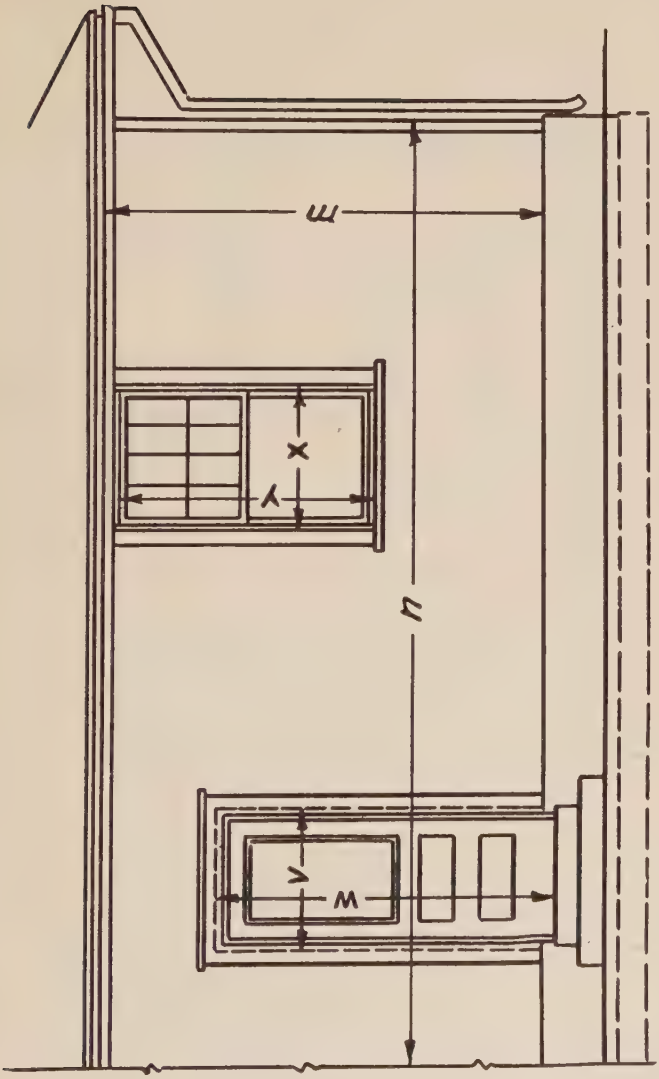


Fig. 4 (Cont'd).—Parts of Walls for Problems Relating to Heat Loss

temperature as K by some other source of heat supply and that the spaces directly below and above are also heated to this same temperature of 70° F. These assumptions immediately eliminate consideration of loss of heat through the inner walls, floor

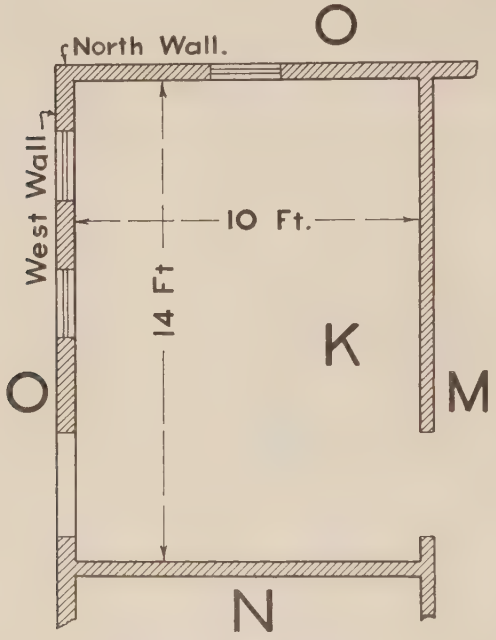


Fig. 5. A Room with Two Exposures for Which Heat Loss Calculations Are Required in Problems Involving Exposure

or ceiling and limit our problem to that of determining the losses through the west and north wall.

The outside or exposed walls as they are commonly called are considered to be constructed of brick 16 in. thick, plastered on the inside. We will first determine the outside areas of the walls, windows and door through which heat will be conducted. The gross area of each wall is:

North wall, 10 ft. (length) x 9 ft. (height) = 90 sq. ft.
West wall, 14 ft. (length) x 9 ft. (height) = 126 sq. ft.

In the north wall there is one window 2 ft. wide x 4½ ft. high, with area of 9 sq. ft. The window

and door sizes should always be taken as equal to the gross opening in the wall. In the west wall there are two windows of the same size as in the north wall and one door 3 ft. x 7 ft., with a total combined window and door area of 39 sq. ft. Deducting these areas from the above gross wall areas, the net wall area is obtained as follows:

Net area of north wall= 90 sq. ft.— 9 sq. ft.=81 sq. ft.
Net area of west wall=126 sq. ft.—39 sq. ft.=87 sq. ft.

The heat transmission coefficient for this type of wall by Table 4 is 0.24. The heat loss through each wall may be calculated as follows:

	Area	Temp. Diff.		Per Hour
For north wall—	81 sq. ft.	x 70° x	0.24 B.T.U.	=1361 B.T.U.
For west wall—	87 sq. ft.	x 70° x	0.24 B.T.U.	=1462 B.T.U.

By Table 9, the transmission factor for a window of single-thickness glass in a wooden frame is 1.10 B.T.U. The heat loss through the windows will then be:

	Area	Temp. Diff.		Per Hour
For north window—	9 sq. ft.	x 70° x	1.10 B.T.U.	= 693 B.T.U.
For west window—	18 sq. ft.	x 70° x	1.10 B.T.U.	=1386 B.T.U.

By Table 10, the transmission factor for a wooden door 1¼ in. thick is 0.60 B.T.U. The heat loss through the door in the west wall will then be:

Area		Temp. Diff.		Per Hour
21 sq. ft.	x 70° x	0.60	B.T.U.	= 882 B.T.U.

The total heat loss for this room in B.T.U. per hour for the conditions as stated will be:

From walls, north.....	1361
From walls, west.....	1462
From windows, north.....	693
From windows, west.....	1386
From door, west.....	882
	5784

Work Problem No. 38.

	A	B.T.U.
PLAIN BRICK	8	0.38
	12	0.29
	16	0.25
	20	0.22
	24	0.19
	28	0.17
	32	0.15
	36	0.14
BRICK, FURRED, LATHED & PLASTERED	8	0.28
	12	0.24
	16	0.21
	20	0.19
	24	0.16
	28	0.15
	32	0.13
	36	0.12
HOLLOW TILE PLASTERED ONE SIDE	4	0.57
	6	0.50
	8	0.36
	10	0.30
	12	0.23
STUCCO HOLLOW TILE FURRING, LATH & PLASTER	4	0.43
	6	0.40
	8	0.30
	10	0.23
	12	0.20

	A	B.T.U.
BRICK PLASTERED ONE SIDE	8	0.36
	12	0.28
	16	0.24
	20	0.21
	24	0.18
	28	0.16
	32	0.14
	36	0.13
HOLLOW TILE	4	0.64
	6	0.57
	8	0.40
	10	0.35
	12	0.26
STUCCO HOLLOW TILE PLASTER	4	0.50
	6	0.46
	8	0.32
	10	0.26
	12	0.22
4" BRICK HOLLOW TILE	4	0.40
	6	0.35
	8	0.30
	10	0.25
	12	0.20
	16	0.14

	A	B.T.U.
4" BRICK HOLLOW TILE PLASTERED	4	0.30
	6	0.27
	8	0.23
	12	0.18
	16	0.13
4" BRICK CONCRETE	4	0.50
	8	0.40
	12	0.31
	16	0.26
BRICK, CONCRETE FURRED, LATHED & PLASTERED	4	0.36
	8	0.30
	12	0.23
	16	0.18
LIMESTONE PLASTERED ONE SIDE	4	0.94
	6	0.83
	8	0.70
	10	0.65
	12	0.60
	16	0.50
	20	0.41

	A	B.T.U.
4" BRICK HOLLOW TILE FURRED, LATHED & PLASTERED	4	0.24
	6	0.22
	8	0.20
	12	0.17
	16	0.11
4" BRICK CONCRETE PLASTERED	4	0.46
	8	0.36
	12	0.28
	16	0.23
LIMESTONE OR SANDSTONE	6	0.90
	8	0.80
	10	0.70
	12	0.65
	16	0.55
	20	0.47
	24	0.39
LIMESTONE FURRED, LATHED & PLASTERED	4	0.71
	6	0.60
	8	0.53
	10	0.48
	12	0.43
	16	0.36
	20	0.30

	A	B.T.U.
CONCRETE	4	0.85
	6	0.73
	8	0.60
	10	0.54
	12	0.47
	16	0.40
	20	0.33
CONCRETE FURRED, LATHED & PLASTERED	4	0.63
	6	0.57
	8	0.47
	10	0.43
	12	0.40
	16	0.33
	20	0.26
STONE PLASTERED	6	0.79
	8	0.65
	10	0.59
	12	0.51
	16	0.45
	20	0.33
STUCCO WOOD LATHS STUDS WOOD LATHS PLASTED 0.57 B.T.U. WITH METAL LATHS IN PLACE OF WOOD-0.64 B.T.U.		

	A	B.T.U.
CONCRETE PLASTERED	4	0.80
	6	0.71
	8	0.57
	10	0.52
	12	0.45
	16	0.38
	20	0.32
STONE	4	0.99
	6	0.85
	8	0.70
	10	0.64
	12	0.56
	16	0.49
	20	0.39
STONE, FURRED, LATHED & PLASTERED	6	0.56
	8	0.46
	10	0.42
	12	0.39
	16	0.32
	20	0.25
TWO 1" BOARDS ON STUDS WITH SAWDUST BETWEEN	2	0.121
	4	0.083
	6	0.062
	8	0.049

H. A. V. E. G. 1924-25

TABLE 4. HEAT TRANSMISSION FROM VARIOUS TYPES OF WALL CONSTRUCTION

The following eight-step form should be used in submitting solutions for problems involving the calculation of the total heat loss from a wall containing window and door openings.

First: Calculate in square feet, the gross exposed wall area (that is, include all openings).

Second: Calculate in square feet, the area of each opening.

Third: Subtract result Second from result First and obtain the Net Wall Area.

Fourth: Select from proper tables, the proper heat transmission factor for the type of wall and openings.

Fifth: Subtract the outside temperature from the inside temperature.

Sixth: Multiply the Net Wall Area found in Third by the transmission factor from Fourth and this product by result Fifth and obtain the heat loss per hour in B.T.U. for the wall.

Seventh: Multiply the Area of each opening (or combined) found in Second by the proper transmission factor from Fourth and this product by the result Fifth and obtain heat loss per hour in B.T.U. for each opening (or total).

Eighth: Add results Sixth and Seventh and obtain the total heat loss from the wall in B.T.U.

Work Problems Nos. 39, 40 and 41.

EFFECT OF EXPOSURE

Exposure is an important factor. It may carry much weight when applied to calculations for one room such as we have just been considering. But when considered for an entire house, its effect may be multiplied many times.

Reference to Fig. 6 will assist toward a clearer conception of this factor. Here are shown two ground plans; A, representing a square type, with B representing a spread-out type. The area of A is equal to that of B; each representing 1296 sq. ft., so, for the same ceiling heights, the cubical contents will be equal. But the running feet of exposure is 144 ft. for A, while B has 178 ft. or an increase of 23.6%. It is essential therefore that consideration be given exposure.

In this hemisphere, the south side of a house upon which the sun shines, will show during the day, an average temperature higher than on the north side. This fact is called Exposure, and should properly be

Construction	B.T.U.
Clapboard on Studs	0.62
Clapboard on Studs, Lath and Plaster	0.48
Clapboard, Paper, Studs, Lath and Plaster	0.34
Clapboard, Studs, 1" Sheathing	0.57
Clapboard, Sheathing, Studs, Lath and Plaster	0.37
Clapboard, Paper, Sheathing, Studs, Lath and Plaster	0.30
Clapboard, Studs, Brick Fill	0.40
Clapboard, Studs, Brick Fill, Papered	0.36
Clapboard, Studs, Brick Fill, Lath and Plaster	0.31
Clapboard, Sheathing Studs, Lath and Plaster with Sawdust Fill	0.21
Clapboard, Paper, Sheathing, Studs, Lath and Plaster with Sawdust Fill	0.15

H. & V. E. G. 24-25

TABLE 5. HEAT TRANSMISSION FROM WALLS OF CLAPBOARD CONSTRUCTION

Assume the Ground Temperature to be 50° Fahr.

Construction	Btu
4" Concrete, Ground	0.31
4" Concrete, Cinder Fill, Ground	0.29
1" Tile, 4" Concrete, Ground	0.30
2½" Brick, 4" Concrete, Ground	0.29
1½" Wood Floor, Waterproofing, 3" Concrete, Ground	0.10
1½" Wood Floor, 3" Concrete, Cinder Fill, Ground, Sleepers	0.07
1½" Wood Floor, 5" Cinder Fill, Ground, Sleepers	0.11
1½" Wood Floor, Air Space, Ground, Sleepers	0.13

H & V E G 24-25

Assume Temperature of Unheated Air Space Above to be 35° Fahr Above the Outside Temperature

Construction	Btu
Unheated Space, Joists, Lath, Plaster	0.60
Floor, Joists, Lath, Plaster	0.26
Floor, Joists, Metal Ceiling	0.36
1" Floor, Joists	0.40
Floor, Paper, Floor, Joists	0.21
Floor, 4" Reinforced Concrete	0.41
4" Reinforced Concrete	1.00
6" Reinforced Concrete	0.86
8" Reinforced Concrete	0.41
10" Reinforced Concrete	0.36

H. & V. E. G. 24-25

TABLES 6 AND 7. HEAT TRANSMISSION FROM FLOORS AND CEILINGS

TABLE 13—EXPOSURE FACTORS*

Buildings well-constructed and subjected to only reasonable exposure.			Poorly-constructed; or well-constructed building subjected to high winds and low temperatures.	
For unventilated room, increase heat loss by per cent. below.	For ventilated room, increase heat loss by per cent. below.	Exposure	For unventilated room, increase heat loss by per cent. below.	For ventilated room, increase heat loss by per cent. below.
15	25	North	25	35
10	20	West	20	30
10	20	East	20	30
0	10	South	10	20

* The factors given are not based on experimental research, but are considered safe to use to assure ample heat supply when needed. Geographical location should be taken into consideration when applying them. In the warmer sections of the United States the factors might very properly be reduced one-half.

taken into consideration in calculating heat losses, for when the north and west wall surfaces of a building are subjected to heavy winds and low temperatures, tne amount oi cold air leaking in through the wall, and the amount of heat carried away by the increased air currents brushing against the outside walls, will be materially increased.

It is difficult to give concrete data that could be applied with absolute accuracy, so it is the practice of many engineers to increase the calculated heat transmission loss of the wall and glass surface by a certain percentage in all cases. If buildings are well-constructed, and located so as to be subjected to only reasonable exposure, that is, so situated that they are somewhat protected from high winds by the proximity of other buildings, the exposure factors may be lower than for buildings that are located in the open where high winds are of frequent occurrence during the winter months.

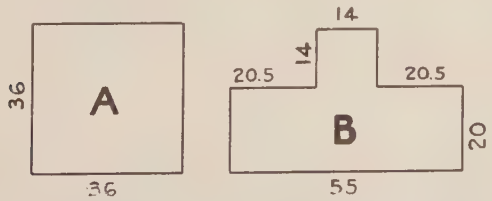
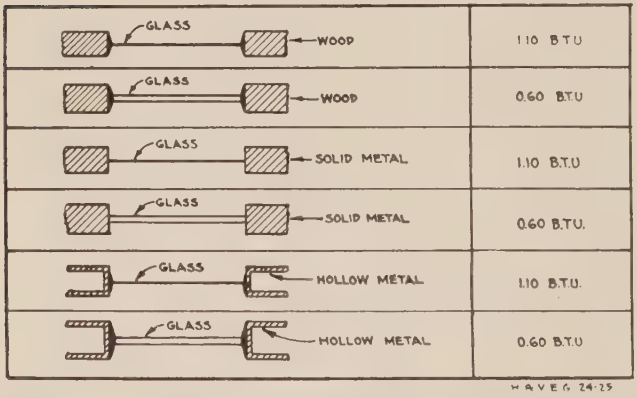


Fig. 6. Houses with the Same Ground Area but with Different Exposed Area Will Have Different Heat Requirements

Construction	B. T. U.
1" Wood, 5 Ply Paper, Tar and Gravel	0.30
1" Wood, Felt Roofing	0.36
1½" Wood, 5 Ply Paper, Tar and Gravel	0.26
2" Wood, 5 Ply Paper, Tar and Gravel	0.21
2½" Wood, 5 Ply Paper, Tar and Gravel	0.18
Tin on Wood Strips	1.60
Tin on Sheathing	0.60
Tin on Sheathing, with Paper	0.43
Shingles on Wood Strips	0.87
Shingles on Sheathing	0.43
Shingles, Paper, Sheathing, Strips	0.21
4" Hollow Tile, Paper, Tar and Gravel	0.30
6" Hollow Tile, Paper, Tar and Gravel	0.27
2" Concrete, Paper, Tar and Gravel	0.71
3" Concrete, Paper, Tar and Gravel	0.64
4" Concrete, Paper, Tar and Gravel	0.57
Flat Tile on Wood Strips	1.07
Flat Tile on Sheathing	0.64
Slate on Wood Strips	1.10
Slate on Paper and Sheathing	0.50
Corrugated Iron on Strips	1.50
Corrugated Iron, Sheathing	0.64

H.B.V.E.G-24-25

TABLE 8. HEAT TRANSMISSION FROM ROOFS



H.&V.E.G. 24-25

TABLE 9. HEAT TRANSMISSION FROM WINDOWS, ROOF GLASS, AND SKYLIGHT

Then again, if provision is made to ventilate the room, the factors should be higher than where no special means are provided for introducing fresh air continuously. A study of data in Table 13 and application of the data to the room shown as Fig. 5 should make this subject clear.

Heat Transmission from Wood Doors & Wood Partitions	B.T.U.
¾" to 1" Thick Tongued and Grooved	0.65
1" to 1¼" " " " "	0.60
1¼" to 1½" " " " "	0.50
1½" to 2" " " " "	0.42
2" to 2½" " " " "	0.35
2½" to 3" " " " "	0.30

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Table 10. Heat Transmission from Wood Doors and Wood Partitions

Thickness of Board in Ins.	Two Boards with Paper Between	Board & Corrugated Iron	Board & Sheet Iron
½"	0.32 B.T.U.	0.45 B.T.U.	0.50 B.T.U.
1"	0.24 B.T.U.	0.36 B.T.U.	0.40 B.T.U.
1½"	0.19 B.T.U.	0.30 B.T.U.	0.33 B.T.U.
2"	0.16 B.T.U.	0.26 B.T.U.	0.28 B.T.U.
2½	0.14 B.T.U.	0.23 B.T.U.	0.25 B.T.U.

H. & V. E. G. 24-25

Table 11. Heat Transmission from Walls of Various Construction

Construction	B.T.U.
Plaster, Lath, Studs, Lath and Plaster	0.34
Studs, Lath and Plaster	0.60
4" Hollow Tile, Plastered 1 Side	0.57
4" Hollow Tile, Plastered Both Sides	0.50
2" Gypsum Block, Plastered 1 Side	0.64
2" Gypsum Block, Plastered Both Sides	0.60

H. & V. E. G. 24-25

Table 12. Heat Transmission from Interior Walls

The room of Fig. 5 has a north and west exposure. We will assume that it is part of a well-constructed building standing in the open, no special means being provided for ventilation other than the ordinary leakage around windows and doors (which is covered below) and that obtained by opening of the door. The heat loss calculations should then be increased by 25% for the north wall and 20% for the west wall, taken from Table 13, which will give the following:

	Per Hour
For north wall (1361 + 693) x 1.25	= 2568 B.T.U.
For west wall (1462 + 1386 + 882) x 1.20	= 4476 B.T.U.
Total heat loss	= 7044 B.T.U.

Thus, by considering the effect of exposure upon the heat requirements, we must supply 7044 B.T.U. per hour instead of 5784 B.T.U. per hour. A design based on the larger figure is just that much safer than that in which exposure is not considered.

Work Problems Nos. 42, 43, 44 and 45.

PART 1.

FUNDAMENTALS OF HEATING

LESSON 3.

Heat Loss Computations

HEAT LOSS COMPUTATIONS.

Various formulas and methods have been presented for calculating heat loss upon which to base radiation requirements. The only method by which nearest to accurate results may be obtained is very properly termed the B.T.U. method. Accuracy of results obtained with this method depends principally on the accuracy of the designer in computing the areas of the surfaces and how close the transmission factor used agrees with that which would be obtained if a section of the construction for which computations were being made had been used in determining the factor. Since this is obviously impossible, factors, as given in Tables 4 to 12 (Lesson 2) and developed for a similar type of construction are used, although the materials composing the test wall might have had slightly different characteristics.

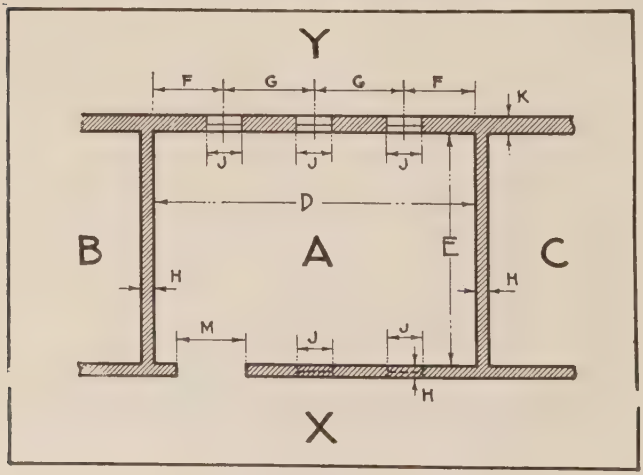
It was explained in Lesson 1 how the heat contained in a warm object will gradually be transferred to one having a lower temperature until the temperatures of the two objects are equal.

In this manner, heat will pass from a warm room, (a) to a colder room, (b) to the outside air, (c) to the attic, (d) and to any other adjacent space where the temperature is lower than that maintained in the heated room. Also, in a similar manner, heat will be absorbed by a room from an adjacent space if the space is maintained at a higher temperature than the room. Consequently, in calculating heat loss for upper story rooms having cold attics above, the loss through the ceiling should always be considered. In like manner, heat calculation losses for rooms with unheated space under them should always include the loss through the floor.

Therefore, to obtain the net B.T.U. loss for a heated room, all surfaces or constructions that separate the room from a space in which the temperature is lower than in the room are counted as positive heat losses and all surfaces or constructions that separate the room from a space in which the temperature is higher than in the room are counted as negative heat losses. The algebraic sum of all positive and negative heat losses will be the net B.T.U. loss from the room without consideration of exposure.

An exposure factor should be included in all calculations for outside walls, windows and doors. It need not be considered when figuring for inside walls, windows, doors, ceilings or floors.

Fig. 7.—Typical Room Plan for Demonstrating B.T.U. Method of Heat-Loss Calculations



APPLICATION OF B.T.U. METHOD

Fig. 7 represents a typical room by the use of which the application of the B.T.U. method of computing heat loss calculations may be clearly understood.

It is assumed that the temperature in room A is to be maintained at 70° F. and that the net heat loss therefrom in B.T.U. per hour is desired. Space Y represents outside air space, minimum temperature, zero deg. F.; B and C are adjoining rooms, temperature of B, 60° F., temperature of C, 65° F.; space X represents a hall at 40° F. Dimensions of the walls, windows and doors and the other conditions are as follows:

D = 30 ft.; E = 22 ft.

K = 12-in. brick wall, plastered inside, (see Table 4).

H = Stud partition, lath and plaster both sides, (see Table 12).

J = Windows, 4 ft. × 5 ft. openings, wood frame, single glass (see Table 9).

M = Door, 4 ft. × 7 ft., 1⅜ in. thick (see Table 10).

Ceiling, 10 ft. high, lath and plaster on joists. (see Table 7) (attic above unheated assume temp. 35°).

Floor, 1½ in. thick on sleepers laid on 5″ cinder fill on the ground, (see Table 6).

Disregard windows J in wall between A and X.

Assume a ventilated room, northern exposure, (see Table 13) (well-constructed subject to reasonable exposure).

NOTE: In solving the application problems for this section, the work should be presented in as full detail as the solution of the demonstration problem, directly following.

DEMONSTRATION PROBLEM—SOLUTION

Wall between A and Y.

Gross area of wall = 30 ft. × 10 ft. = 300 sq. ft.

Area windows 3 × (4 ft. × 5 ft.) = 60 sq. ft.

Net area of wall 300 — 60 = 240 sq. ft.

Temperature difference = 70° — 0° = 70° F.

Heat loss for wall = 240 (sq. ft.) × 70 (temp. diff.) × 0.28 (factor) = 4704 B.T.U.

Exposure allowance for wall = 4704 × 0.25 = 1176 B.T.U.
Total loss for wall = 4704 + 1176 = 5880 B.T.U.
Heat loss for windows = 60 (sq. ft.) × 70 (temp. diff.) × 1.10 (factor) = 4620 B.T.U.
Exposure loss for windows = 4620 × 0.25 = 1155 B.T.U.
Total loss for windows = 4620 + 1155 = 5775 B.T.U.
Total loss from A to Y = 5880 + 5775 = 11,655 B.T.U.

Wall between A and B.
Gross area of wall = 22 ft. × 10 ft. = 220 sq. ft.
Area of openings = none.
Net area of wall = 220 sq. ft.
Temperature difference = 70° — 60° = 10° F.
Heat loss from A to B = 220 (sq. ft.) × 10 (temp. diff.) × 0.34 (factor) = 748 B.T.U.

Wall between A and C.
Gross area of wall = 22 ft. × 10 ft. = 220 sq. ft.
Area of openings = none.
Net area of wall = 220 sq. ft.
Temperature difference = 70° — 65° = 5° F.
Heat loss from A to C = 220 (sq. ft.) × 5 (temp. diff.) × 0.34 (factor) = 374 B.T.U.

Wall between A and X.
Gross area of wall = 30 ft. × 10 ft. = 300 sq. ft.
Area of door = 4 ft. × 7 ft. = 28 sq. ft.
Net area of wall = 300 — 28 = 272 sq. ft.
Temperature difference = 70° — 40° = 30° F.
Heat loss for wall = 272 (sq. ft.) × 30 (temp. diff.) × 0.34 (factor) = 2774 B.T.U.
Heat loss for door = 28 (sq. ft.) × 30 (temp. diff.) × 0.50 (factor) = 420 B.T.U.
Total loss from A to X = 2774 + 420 = 3194 B.T.U.

Floor.
Gross area of floor = 30 ft. × 22 ft. = 660 sq. ft.
Temperature difference = 70° — 50° = 20° F.
Heat loss thru floor = 660 (sq. ft.) × 20 (temp. diff.) × 0.11 (factor) = 1452 B.T.U.

Ceiling.
Gross area of ceiling = same as floor = 660 sq. ft.
Temperature difference = 70° — 35° = 35° F.
Heat loss thru ceiling = 660 (sq. ft.) × 35 (temp. diff.) × 0.60 (factor) = 13,860 B.T.U.

All Losses—From A to Y = 11,655 B.T.U.
A to B = 748 B.T.U.
A to C = 374 B.T.U.
A to X = 3,194 B.T.U.
Floor = 1,452 B.T.U.
Ceiling = 13,860 B.T.U.

Total from Room = 31,283 B.T.U.

Work Problems Nos. 46, 47 and 48

TABLE 14. SPECIFIC HEAT VALUES FOR VARIOUS SUBSTANCES

SUBSTANCE		SPECIFIC HEAT	SUBSTANCE		SPECIFIC HEAT
LIQUIDS	WATER	1.0000	BUILDING MATERIALS	BRICKWORK	0.1950
	ALCOHOL	0.6220		MASONRY	0.2000
	TURPENTINE	0.4720		PLASTER	0.2000
	OLIVE OIL	0.3090		PINE WOOD	0.4670
	PETROLEUM	0.4340		OAK WOOD	0.5700
				BIRCH	0.4800
				GLASS	0.1977
METALS	CAST IRON	0.1298			
	WROUGHT IRON	0.1138			
	SOFT STEEL	0.1165			
	COPPER	0.0951			
	BRASS	0.0939		CONSTANT PRESSURE	CONSTANT VOLUME
	TIN	0.0569			
	LEAD	0.0314	GASES	AIR	0.2415	0.1729
	ALUMINUM	0.2185		OXYGEN	0.2175	0.1550
	ZINC	0.0953		HYDROGEN	3.4090	2.4122
				NITROGEN	0.2438	0.1727
				STEAM	0.5000	0.3500
MINERALS	COAL	0.2777		CARBONIC ACID CO.	0.2479	0.1758
	MARBLE	0.2159		AMMONIA	0.5080	0.2990
	CHALK	0.2149				
	STONES, GENERAL	0.2100				
	LIMESTONE	0.2170				

SPECIFIC HEAT VALUES

Specific heat was defined and explained in Lesson 1. In Table 14 specific heat values for various substances are given. These values have been determined experimentally.

The quantity of heat added to or removed from a body is equal to the product of the weight of the body in pounds, multiplied by the specific heat of

the material of which the body is composed and this product multiplied by the temperature range in degrees, through which the body has passed.

Thus the quantity of heat added to or removed from a body may be calculated as follows:

First: Determine the weight of the body in pounds.

Second: Select a specific heat value corresponding to the material.

Third: Determine the increase or decrease in the temperature of the body.

Fourth: Multiply First by Second by Third and obtain the heat units added to or taken from the body.

APPLICATION OF SPECIFIC HEAT VALUES

When steam or water is first admitted into the heating system, the temperature of radiators and piping must first be brought to the temperature of the heating medium. The quantity of heat required to raise the temperature of a 300 lbs. cast-iron radiator to that at which it is to operate may be determined by applying the four-step form above as follows:

First: Weight of body = 300 lbs.

Second: Specific heat of cast-iron = 0.1298 (by Table 14).

Third: Initial temperature of radiator = 50° F.
Temperature steam at 5.3 lbs./sq. in. pressure, (gage) = 228° F.
Increase in temperature = 228 — 50 = 178° F.

Fourth: Heat units required = 300 × 0.1298 × 178 = 6930 B.T.U.

Work Problems Nos. 49 and 50

HEAT REQUIREMENTS OF BUILDINGS

INTERMITTENTLY HEATED

Buildings such as churches and large assembly halls which are heated intermittently require special consideration as to heating requirements. Before the temperature within can be maintained at that desired for the comfort of the occupants, a sufficient quantity of heat must be introduced to change the temperature of the integral parts of the structure

itself. With a plant of sufficient capacity, the temperature within can be brought to the desired point in a reasonable length of time. If the plant is too small, fires, in very cold weather, must be started many hours before the building is to be used and it is not infrequent that the temperature in some structures is considerably lower than that desired at the hour when the occupants arrive.

TABLE 15

PROPERTIES OF AIR

TEMP. °F.	VOLUME OF DRY AIR WITH UNITY AT 32° F.	SPECIFIC VOLUME. CU. FT. IN 1 LB. OF AIR	SPECIFIC DENSITY. WEIGHT OF 1 CU. FT. OF DRY AIR	ELASTIC FORCE OF VAPOR INS. OF MERCURY	FEET OF VAPOR FROM 1 LB. OF WATER	B.T.U. ABSORBED BY 1 CU. FT. OF AIR PER DEGREE F.		CU. FT. OF AIR RAISED 1° F. BY 1 B.T.U.	
						DRY AIR	SAT. AIR	DRY AIR	SAT. AIR
1	2	3	4	5	6	7	8	9	10
0	0.935	11.58	0.0864	0.044	—	0.02056	0.02054	48.5	48.7
12	0.960	11.87	0.0842	0.074	—	0.02004	0.02006	50.1	50.0
22	0.980	12.14	0.0824	0.118	—	0.01961	0.01963	51.1	51.0
32	1.000	12.40	0.0807	0.181	32.89	0.01921	0.01924	52.0	51.8
42	1.020	12.64	0.0791	0.267	22.52	0.01882	0.01884	53.2	52.8
52	1.041	12.88	0.0776	0.388	15.95	0.01847	0.01848	54.0	53.8
60	1.057	13.09	0.0764	0.522	12.27	0.01818	0.01822	55.0	54.6
62	1.061	13.13	0.0761	0.556	11.35	0.01811	0.01812	55.2	54.7
70	1.078	13.34	0.0750	0.754	8.82	0.01777	0.01794	56.3	55.5
72	1.082	13.39	0.0747	0.785	8.19	0.01767	0.01790	56.5	55.8
82	1.102	13.64	0.0733	1.092	6.00	0.01744	0.01770	57.2	56.5
92	1.122	13.90	0.0720	1.501	4.44	0.01710	0.01751	58.5	57.1
100	1.139	13.95	0.0710	1.929	3.56	0.01690	0.01735	59.1	57.8
102	1.143	14.14	0.0707	2.036	3.34	0.01682	0.01731	59.5	57.8
112	1.163	14.40	0.0694	2.731	2.53	0.01651	0.01711	60.6	58.5
122	1.184	14.65	0.0682	3.621	1.94	0.01623	0.01691	61.7	59.1
132	1.204	14.90	0.0671	4.752	1.51	0.01596	0.01670	62.5	59.9
142	1.224	15.15	0.0660	6.165	1.18	0.01571	0.01652	63.7	60.6
152	1.245	15.40	0.0649	7.930	0.93	0.01544	0.01634	65.0	61.5
162	1.265	15.65	0.0638	10.099	0.74	0.01518	0.01616	66.2	62.4
172	1.285	15.90	0.0628	12.758	0.59	0.01494	0.01598	67.1	63.3
182	1.306	16.17	0.0618	15.960	0.48	0.01471	0.01580	68.0	64.2
192	1.326	16.42	0.0619	19.828	0.38	0.01449	—	68.9	—
202	1.347	16.67	0.0600	24.450	0.32	0.01426	—	69.5	—
212	1.367	16.92	0.0591	29.921	0.27	0.01406	—	71.4	—

It is important, therefore, that consideration be given this feature of heating requirements especially for such buildings when the interval between use is long enough to permit all parts of the building to have become entirely cooled.

Problems of this kind should be solved by calculating the total weight of the different materials of

which the structure is composed such as stone work, woodwork, slate, plaster, air, etc. and then determining the number of heat units required to raise the temperature of all substances, as explained above in the case of a radiator. After computing the total heat required, a percentage is added to care for furnishings.

Fig. 8.—General Dimensional Notes for a Church for Demonstrating Heating Requirements of Buildings Intermittently Heated

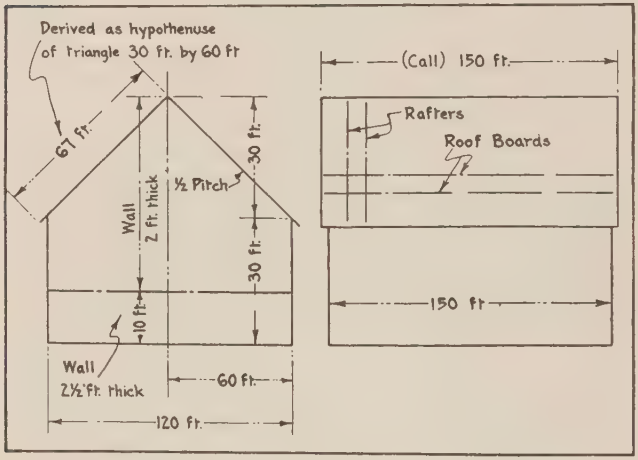


Fig. 8 shows the general shape and dimensions of a church for which it is desired to know the quantity of heat required to raise the temperature of the structure and contents when it has been unheated for a period of such length that all parts have become cooled to the outside temperature.

Work Problem No. 51

Having determined the number of heat units required to raise the temperature of a structure and its contents to that at which it is to be maintained, it is only necessary to know the capacity of the heating plant in order to estimate the time at which heating must be started so that the room will be comfortable when the first occupants arrive.

If it is assumed that 120,000,000 B.T.U. are required to raise the temperature of a given structure to its desired temperature and the plant is capable of supplying heat at the rate of 30,000,000 B.T.U.

per hour, 4 hours would be required, providing there was no transmission of heat to the outside. Since this will always occur whenever the temperature within differs from that without, a percentage may be added to estimate for this loss. If the total heat units required be increased 50% and this figure divided by the capacity of the plant the result will be a fair average of the time required. If the outside temperature is very low and a high wind is blowing more time will be needed.

Work Problem No. 52

INFILTRATION OR LEAKAGE

To make computations for heat losses by the B.T.U. method as nearly correct as possible, a quantity which has not been considered so far in the course, known as INFILTRATION OR LEAKAGE should be included. By INFILTRATION is meant the quantity of outside air which may enter by "filtering in" or leaking into a room through the cracks or clearances around windows and doors or through the walls themselves, especially when the building is of poor workmanship.

The heat necessary to take care of this infiltration is that required to warm the outside air which filters in and to raise its temperature from that outside to the inside temperature.

As when calculating transmission losses, the time unit is taken as one hour. The quantity of air is usually expressed as its weight in pounds.

This quantity of air that enters through building construction cracks, openings around windows and doors, etc., is often of considerable moment and introduces a factor which, if not provided for in heating plant capacity, will result in poor and unsatisfactory service, especially in severe weather. Each installation presents a particular problem and should have due consideration.

The volume of air entering a building as in-leakage is not susceptible to very precise calculation. It depends upon the width of crack opening, total lineal feet of opening and wind velocity. Infiltration losses can be materially reduced by the use of storm doors and windows, metal weather-stripping on doors and windows, by calking around doors and

casing in frame construction; by close-fitting tongue-and-groove strips covered with heavy building paper, and by using insulating material in the wall construction.

Specific density or weight of air was explained in Lesson 1 and it was shown there that as a unit volume of air becomes warmer, its weight becomes less. All in-leaking air must be heated from the outside air temperature to that of the heated room. By Table 15, Properties of Air, it is noted by column 4 that 1 cu. ft. of air at zero degrees weighs 0.0864 lbs. while at 70° F., the same volume weighs only 0.0750 lbs. Therefore, by dividing 0.0750 by 0.0864, it is found that 0.87 cu. ft. of air at 0° F. becomes 1 cu. ft. when heated to 70° F.

Work Problem No. 53

The specific heat of air as commonly used is 0.24. Therefore, to raise 0.87 cu. ft. of air from 0° F. to 70° F., the heat units required will be

0.075 (lbs.) × 0.24 (sp. ht.) × 70 (deg.) = 1.260 B.T.U.

Work Problem No. 54

Two methods for figuring infiltration losses are at present used by heating engineers. The more common method is to estimate the infiltration of air into a building in terms of the number of air changes or number of times per hour the air which

TABLE 16. AIR CHANGES PER HOUR

Space	Air changes per hour.
Halls, first floor	2 to 3
Halls, second floor	1
Halls, living room	2 to 3
Living rooms	1 to 2
Living rooms with fireplace, without damper	2 to 4
Dining rooms	1 to 2
Sleeping rooms	1
Bath and serving room	2
Kitchen and offices	1 to 2
Drug stores	2 to 3
Clothing stores	1
Churches and assembly rooms	1 to 2
Factories, lofts, etc.	1 to 2

leaks in displaces the air in the room. The other method is to use the lineal feet of window and outside door cracks, and assume a maximum width of opening. The lineal feet of crack method is probably more accurate, since it considers the relation of the glass area to the cubical contents of the room. This method involves more work in calculation, though, which probably accounts for the air-change method being more generally used. In cases, though, where combined glass and door area is small in proportion to the cubical contents, the heat loss calculated on basis of lineal feet of crack should be checked against the air-change method to be sure that it is not less than the equivalent for one air change per hour.

TABLE 17

B.T.U. REQUIRED PER CUBIC FOOT FOR VARIOUS AIR CHANGES AND TEMPERATURE CHANGES

TEMP. RISE °F.	NUMBER AIR CHANGES PER HOUR								
	½	1	1½	2	3	4	5	6	10
1	2	3	4	5	6	7	8	9	10
5	0.05	0.09	0.14	0.18	0.27	0.36	0.45	0.55	0.91
10	0.09	0.18	0.27	0.36	0.55	0.73	0.91	1.09	1.82
15	0.14	0.27	0.41	0.55	0.82	1.09	1.36	1.64	2.73
20	0.18	0.36	0.55	0.73	1.09	1.45	1.82	2.18	3.64
25	0.23	0.45	0.68	0.91	1.36	1.82	2.27	2.73	4.55
30	0.27	0.55	0.82	1.09	1.64	2.18	2.73	3.27	5.45
35	0.32	0.64	0.95	1.27	1.91	2.55	3.18	3.82	6.36
40	0.36	0.73	1.09	1.45	2.18	2.91	3.64	4.36	7.27
45	0.41	0.82	1.23	1.64	2.45	3.27	4.09	4.91	8.18
50	0.45	0.91	1.36	1.82	2.72	3.64	4.55	5.45	9.09
55	0.50	1.00	1.50	2.00	3.00	4.00	5.00	6.00	10.00
60	0.55	1.09	1.64	2.18	3.27	4.36	5.45	6.55	10.91
65	0.59	1.18	1.77	2.36	3.54	4.72	5.91	7.09	11.82
70	0.64	1.27	1.91	2.54	3.82	5.09	6.36	7.64	12.72
75	0.68	1.36	2.05	2.73	4.09	5.45	6.82	8.18	13.63
80	0.73	1.45	2.18	2.91	4.36	5.82	7.27	8.72	14.54
85	0.77	1.55	2.32	3.09	4.64	6.17	7.73	9.27	15.45
90	0.82	1.64	2.46	3.27	4.91	6.55	8.18	9.83	16.36

INFILTRATION BY THE AIR-CHANGE METHOD

In Table 16, values are given for the number of air changes per hour commonly used in several types of buildings and rooms.

If we assume the room of Fig. 5 to represent a living room, and allow two air changes per hour, the volume of the room being 10 ft. $\times$ 14 ft. $\times$ 9 ft. $=$ 1260 cu. ft., the total air entering per hour

will be twice this quantity, or 2520 cu. ft. It requires approximately 0.02 B.T.U. to raise the temperature of 1 cu. ft. of air at 0° F. to 1° F. Therefore, since this 2520 cu. ft. must have its temperature raised from 0° F. to 70° F, the total heat units required to care for infiltration on this basis will be 2520 (cu. ft.) × 70 (temp. diff.) × 0.02 (B.T.U.) = 3528 B.T.U. per hour.

Work Problem No. 55

The use of Table 17 will be found convenient in calculating infiltration requirements by the air-change method. This table shows the number of heat units required per cubic foot for different air changes and temperature rises.

If infiltration demands are to be calculated on the basis of one air change for a room 15 ft. × 15 ft. × 10 ft. maintained at 70° F. when the outside temperature is 0° F., procedure is as follows:

Temperature rise = 70° — 0° = 70° F.
Cubical contents = 15 × 15 × 10 = 2250 cu. ft.
Factor from table = 1.27.
B.T.U. for leakage = 2250 × 1.27 = 2857 B.T.U.

Table 18

WINDOW LEAKAGE DATA

	LEAKAGE, C.F.M. CRACK PERIMETER 18 FT. 4 INS.				B.T.U. PER HOUR							
					0 - 70 DEG. F.				20 - 70 DEG. F.			
	FOR TOTAL WINDOW		PER FT. CRACK		FOR TOTAL WINDOW		PER FT. CRACK		FOR TOTAL WINDOW		PER FT. CRACK	
WIND VELOCITY M.P.H.	14.4	24.9	14.4	24.9	14.4	24.9	14.4	24.9	14.4	24.9	14.4	24.9
PLAIN WINDOW												
VERY TIGHT-UNLOCKED	19.0	40.0	1.04	2.18	1445	3040	78.7	166.0	1033	2170	56.3	118.5
TIGHT-UNLOCKED	22.0	46.0	1.20	2.53	1673	3500	91.3	192.5	1195	2500	65.2	137.5
1/16 TO 1/4" CRACK-UNLOCKED	46.0	75.0	2.53	4.08	3500	5700	192.5	310.0	2500	4075	137.5	222.0
RIB WEATHER STRIP												
1/16" CRACK	9.0	20.0	0.49	1.09	685	1522	37.3	83.0	488	1087	26.6	59.2
1/8" CRACK	11.0	22.5	0.60	1.25	837	1710	45.6	95.1	598	1223	32.6	67.9
3/16" CRACK	15.0	30.0	0.82	1.63	1141	2282	62.2	124.4	815	1630	44.4	88.8
1/4" CRACK	18.0	36.0	0.98	1.96	1370	2740	74.7	149.4	978	1956	53.3	106.6
INTERLOCKING WEATHER STRIP												
1/16" CRACK	7.0	16.0	0.38	0.87	533	1218	29.0	66.3	380	870	20.7	47.3
1/8" CRACK	8.5	18.0	0.46	0.98	647	1370	35.3	74.7	462	978	25.2	53.3
3/16" CRACK	9.0	19.5	0.49	1.06	685	1483	37.3	80.9	489	1060	26.6	57.8
1/4" CRACK	10.0	20.5	0.55	1.12	761	1560	41.4	85.0	543	1114	29.6	60.7

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TABLE 19

WINDOW LEAKAGE DATA

DOUBLE HUNG WINDOW

LEAKAGE —CU. FT. PER HOUR PER FOOT OF CRACK PER MILE OF WIND VELOCITY
B.T.U. PER HOUR PER FOOT OF CRACK PER MILE OF WIND VELOCITY PER 70° F. TEMP. DIFF.

CLEARANCE — CRACK INS.	PLAIN		INTERLOCKING TYPE WEATHER STRIPPING.							
	1/16" – 1/4"		1/16"		1/8"		3/16"		1/4"	
	LKG.	B.T.U.	LKG.	B.T.U.	LKG.	B.T.U.	LKG.	B.T.U.	LKG.	B.T.U.
1/32	4.3	5.45	1.32	1.67	1.48	1.87	1.63	2.07	1.79	2.27
1/16	6.6	8.36	1.56	1.98	1.72	2.18	1.88	2.39	2.05	2.59
3/32	8.9	11.90	1.67	2.11	1.83	2.32	2.00	2.54	2.17	2.75
1/8	11.2	14.2	1.71	2.17	1.89	2.39	2.06	2.62	2.24	2.84
3/16	15.7	19.9	1.74	2.20	1.94	2.45	2.13	2.70	2.33	2.95
1/4	20.2	25.6	1.75	2.22	1.96	2.48	2.17	2.75	2.38	3.02

CRACK INS.	RIB TYPE WEATHER STRIPPING							
	1/16"		1/8"		3/16"		1/4"	
	LKG.	B.T.U.	LKG.	B.T.U.	LKG.	B.T.U.	LKG.	B.T.U.
1/32	2.31	2.93	2.51	3.18	2.80	3.55	3.34	4.23
1/16	2.52	3.19	2.71	3.43	3.04	3.85	3.56	4.51
3/32	2.63	3.33	2.83	3.58	3.17	4.02	3.71	4.70
1/8	2.68	3.39	2.89	3.66	3.26	4.12	3.83	4.85
3/16	2.72	3.44	2.95	3.7[illegible]	3.35	4.24	3.98	5.04
1/4	2.73	3.46	2.99	3.78	3.41	4.32	4.10	5.19

H & V. E.G. 1924-25

Work Problem No. 56

Experiments have been conducted to determine the in-leakage of air for various conditions of construction, temperature and wind-velocity. Some of the results obtained by one investigator are given in Tables 18 and 19.

Table 18 shows the leakage in cubic feet per minute for the whole window and per lineal foot of cracks for two wind velocities of 14.4 and 24.9 (approximately 15 and 25) miles per hour, respectively. The effect of weather-stripping is apparent by noting that for a plain window with crack varying from 1/16 to 1/4 in., the leakage was 46 cu. ft. per minute while for two different types of weather stripping it varied from 9 to 18 and 7 to 10 cu. ft. per minute, respectively. Heat loss is given for two temperature differences of 0° and 70° F. and for 20° to 70° F.

Work Problem No. 57

Table 19 shows the leakage in cubic feet per hour per foot of crack per mile of wind velocity for a plain frame window and also for a frame window

fitted with two types of weather-stripping. Leakage is given for various cracks around sash perimeter and also for various clearances between the sash and the stop and parting bead. It will be noted that for a plain window having a clearance of 3/32 in., the leakage in cubic feet per hour per foot of crack per mile of wind velocity is 8.9 and the heat required for a 70° F. temperature difference is 11.9 B.T.U.

In estimating leakage of air through cracks around windows and doors upon which to base heat requirements for raising the temperature of this air from that outside to that inside, it should be appreciated that the total lineal feet of all cracks should NOT be used.

The proper crack area to use in such calculations should be determined for the side of the room in which the greatest number of lineal feet of crack openings occur whether this be on the windward or leeward side of the house. It is thereby assumed that if the greatest total crack area is located on the leeward side, that the air passing to the outside must be replaced by an equal quantity that enters on the windward side.

If the north and west sides be considered as the windward sides of a house and the east and south sides as the leeward sides and each side be considered separately, it will be easy to decide which cracks to use for a given room and the results thus obtained will be as nearly correct as can be reasonably expected.

In some of the assigned problems, directions are given as to the windows and doors that are to be used in figuring infiltration losses. When such instructions are given, they should be observed in working the problems in the course.

Work Problems Nos. 58, 59 and 60

PART 1.

FUNDAMENTALS OF HEATING

LESSON 4.

Rule of Thumb Methods

HEAT LOSS COMPUTATIONS.

RULE-OF-THUMB METHODS.

There are a number of methods or rules used as short cuts for estimating the heat loss by which to proportion the heating surface when direct radiation is to be used. They are often spoken of as "rule-of-thumb" methods. Such rules are intended to be based on average building construction and a ratio of wall and glass surface to the cubical contents of the structure as found in the class of building to which they might be applied.

These rules, when modified for unusual conditions and applied by an engineer with long experience in the proportioning, design and installation of heating systems, may produce satisfactory results. They are passing out of use by the more advanced contractors who use them only for rough approximate estimating or as a quick check for the more refined B.T.U. method covered in Lesson 3.

Rule-of-thumb methods of estimating heat loss should never be used as the basis of calculation for the design of a heating system because all factors that may directly influence the heat loss for different types of walls, different exposure conditions and infiltration losses are not properly considered.

It is advisable, however, that every student of heating and ventilating engineering be informed concerning the application of a few rule-of-thumb methods and to understand how the results obtained from their use for a given structure compare with those obtained by using the B.T.U. method.

Three rule-of-thumb methods will be considered; namely, E.G.S. Method (Equivalent Glass Surface Method); Carpenter's Rule; and Allen's Rule.

EQUIVALENT GLASS SURFACE METHOD (E.G.S. METHOD)

This method is based on the amount of heat transmitted through 1 sq. ft. of glass surface per hour when the inside temperature is 70° F., and the outside is 0° F., or for a temperature difference of 70°. Experiments have shown that 1.2 B.T.U. is a safe heat unit value to use for the heat transmission through 1 sq. ft. of single thickness of glass surface per hour, per degree difference between the inside and outside temperatures, or 70 x 1.2 B.T.U. = 84 B.T.U. for 70° difference between the inside and outside temperatures.

The quantity of heat transmitted through the wall per square foot of surface per hour, for a temperature difference of 70° F., is then assumed to bear a direct relation to the heat transmitted by the glass surface under similar conditions, and from this relation, the number of square feet of wall surface that will transmit the same number of B.T.U. as 1 sq. ft. of glass surface in the same time is established.

This relation will vary for different types of walls, but in applying this rule for ordinary residence construction the walls may generally be considered as limited to the types indicated in Table 20. The relation that exists between the heat transmitted by the glass surface and the wall sur-

face is given for each type of wall. Thus, for example, every 2 sq. ft. area of the wall,—stucco on framing, and plaster finish (last item), will transmit the same amount of heat as 1 sq. ft. of glass surface. One sq. ft. of glass surface will transmit 84 B.T.U. per hour for 70° temperature difference; therefore 1 sq. ft. of wall surface of this type will transmit ½ of 84 B.T.U. or 42 B.T.U. under the same conditions of temperature inside and outside.

TABLE 20. EQUIVALENT WALL SURFACE

(Number of square feet of wall, of type indicated that will transmit same number of B.T.U. per hour as 1 sq. ft. of glass surface under the same conditions.)

Type of Wall	Equivalent Area
Brick, 12 in. thick, plaster inside.....	4
Clapboards, sheathing paper, plaster finish	3
Clapboards, paper, wood sheathing, plaster finish	4
Hollow tile, 8 in., stucco and plaster finish	3
Stucco on framing and plaster finish.....	2

Cubical Contents Factor

Assume 60 cu. ft. of room volume equivalent to 1 sq. ft. of glass surface per air change per hour.

APPLICATION OF THE E.G.S. METHOD

The steps required in the application of this method are enumerated below. (The student should submit work involving this method in this form on sheets supplied for the purpose). Each wall should be considered separately, as north wall, west wall, etc.

First: Determine the number of square feet of exposed glass and door surface in the wall under consideration, multiply by the value 84, and obtain the B.T.U. loss through the glass.

Second: Select a factor from Table 20 corresponding to the type of wall under consideration and divide 84 by this factor.

Third: Determine the net area of exposed wall surface, multiply by result SECOND and obtain the B.T.U. loss through the wall.

Fourth: Apply exposure factors from Table 13, Lesson 2, to results of FIRST and THIRD, when necessary. If no exposure allowance is included, use FIRST and THIRD as calculated above. Thus the total B.T.U. loss from one wall, including exposure is obtained.

Fifth: Consider each of the other exposed walls of the room and proceed as noted under FIRST, SECOND, THIRD and FOURTH.

Sixth: After the B.T.U. loss from each wall has been calculated as noted under FIFTH add the loss for all the walls.

Seventh: Calculate the cubical contents of the room and multiply this by 1.40. This gives the B.T.U. required for one air change. For 1½ air changes, multiply by 2.10. For two air changes multiply by 2.8.

Eighth: If there is an unheated attic over the room (generally known as cold ceiling) assume that 8 sq. ft. of ceiling will transmit the same number of B.T.U. as 1 sq. ft. of glass. Divide 84 by 8 = 10.5 and multiply the result by the area of the ceiling.

Ninth: Add B.T.U. values obtained under SIXTH, SEVENTH and EIGHTH and obtain total B.T.U. loss for room under consideration.

Work Problems Nos. 61 and 62

CARPENTER'S RULE

The following rule which takes its name from that of its author has been widely used in this country. As presented, it is not intended to be applied to buildings covered with corrugated sheet steel or metal lath or plaster walls.

The steps required in the application of this rule are enumerated below. (The student should follow this form in submitting work by this rule on sheet supplied for the purpose).

First: Calculate the volume of the room in cubic feet.

Second: Multiply the result of FIRST by the number of air changes per hour.

Third: Divide the result of SECOND by 55.

Fourth: Calculate the area in square feet of the exposed side (or sides) of the room.

Fifth: Calculate the area in square feet of the windows and door openings in the wall, the area of which was found under FOURTH.

Sixth: Deduct result FIFTH from result FOURTH and get the net exposed wall surface.

Seventh: Divide the result SIXTH by 4.

Eighth: Add the results found under THIRD, FIFTH and SEVENTH.

Ninth: Multiply result EIGHTH by the difference between the inside and outside temperature and obtain the heat loss in B.T.U. for the given conditions.

Work Problem No. 63

ALLEN'S RULE

The following rule which also takes its name from that of its author may be applied in the following steps. (The student should follow this form and submit results on sheet supplied).

First: Calculate the area in square feet of the window and door openings in the exposed wall.

Second: Calculate the area of the exposed wall in square feet.

Third: Subtract result FIRST from result SECOND and get the net area of exposed wall in square feet.

Fourth: Divide the result THIRD by 4.

Fifth: Add the result of FOURTH to result FIRST.

Sixth: Multiply the result FIFTH by the difference between the inside and outside temperature.

Seventh: Multiply result SIXTH by the number of air changes per hour and obtain the heat loss in B.T.U. for given conditions.

Work Problems Nos. 64, 65 and 66

EFFECT OF VENTILATION UPON B.T.U. LOSSES

In calculating heat losses by the different methods discussed the heat required for heating the air supplied for ventilating purposes has not been considered. This may be an important item especially with mechanical ventilating systems.

It is not intended in this part of the course to enter into a discussion of the principles of air conditioning but merely to explain briefly in a general way, how the B.T.U. loss as calculated for transmission and infiltration may be insufficient when it is necessary to introduce additional air in order that a required degree of purity be maintained.

Ventilation, whether NATURAL OR MECHANICAL embodies the displacement of vitiated air from a space and its replacement with fresh air. It should not be considered that the air in a space is completely renewed any given number of times per hour as this is not strictly accurate, since a positive change does not actually occur. What does happen is that the incoming air mixes with and dilutes the foul air to a point suitable for healthful respiration.

To be well ventilated, a room should contain, at all times, air of such volume and purity as will assure the removal of the proper quantity of heat from the human body when clothed normally. The air must have proper characteristics as governed by its temperature, humidity and motion. It must contain oxygen in required quantity to support human life properly, be free from harmful bacteria and low in dust count. It should be free of bodily and other objectional odors and harmful gases. It must be supplied to all parts of the enclosed space in sufficient quantity to provide amply for the required conditions.

TABLE 21—COMPOSITION OF PURE AND RESPIRED AIR

CONSTITUENT	PURE AIR	RESPIRED AIR
OXYGEN	20.26%	16.2%
NITROGEN	78.00%	75.0%
CARBON DIOXIDE	0.04%	4.0%
WATER VAPOR	1.50% VARIABLE	5.0%

R.C. CARPENTER

CARBONIC ACID AS AN INDEX TO COMPARATIVE AIR PURITY

While outside air may be considered as pure, it will not long stay so when inhaled and expired. The composition of pure (comparative) air and respired air is shown in Table 21.

When the air is taken into the lungs, its temperature is that of the room but when expired it has a temperature of from 90° to 98° F. It is also nearly saturated with water vapor and is from 1% to 3% lighter. These changes, however, are not the greatest. Notice that the per cent of carbonic acid has increased about 100 times, or from 4 parts to 400 parts in 10,000 parts.

Work Problem No. 67

As air is exhaled, the gases immediately begin to diffuse and the carbonic acid is soon distributed quite uniformly throughout the air of the room, thereby increasing the content above 4 parts in 10,000. This diffusing continues with an increase in the per cent of carbonic acid gas up to about 7 parts in 10,000 when the effect of poor ventilation is easily apparent. When 10 parts is reached actual discomfort may occur. Therefore it is customary to control this increase in carbonic acid gas content by ventilation; that is, by supplying the number of cubic feet of outside air for each person, necessary to maintain some desirable standard of purity.

An adult at rest requires about 20 cu. in. of air at each respiration and makes from 16 to 24 respirations per minute, so that a total of 320 to 480 cu. in. of air per minute is required for an adult. This is approximately 0.25 cu. ft. For adults exercising, this amount may be increased to 0.33 cu. ft.

This exhaled air contains 4 parts of carbonic acid gas in 100 parts or 400 parts in 10,000 parts. This is 4% or 4 one-hundreths. Therefore an adult at rest gives off 0.25 (cu. ft.) x 60 (minutes) x 0.04 (proportion) = 0.6 cu. ft. of carbonic acid gas per hour.

On this basis 0.60 cu. ft. of carbonic acid gas is produced per hour by an adult at rest. If we assume the proportion of 4 parts in 10,000 in the outside air, and that we may allow 7 parts in 10,000 as safe in an occupied room, then the gain in carbonic acid content after admission to the room will be 3 parts in 10,000. This means that if we divide 3 by 10,000 we will get the cubic feet of carbonic acid

that may be mixed with each cubic foot of fresh air that enters the room before it exceeds the proportion of 7 parts in 10,000. Thus $3 \div 10{,}000 = 0.0003$ cu. ft.

In order to keep the air in a room at the standard of purity assumed:—7 parts in 10,000 parts,—it will be necessary to supply $0.60 \div 0.0003 = 2000$ cu. ft. of air per hour per person.

Work Problem No. 68

TABLE 22—VOLUME OF AIR REQUIRED FOR VARIOUS STANDARDS OF PURITY

STANDARD OF PURITY	CUBIC FEET OF AIR (4 TO 10000) TO BE SUPPLIED PER PERSON	
PARTS OF CO_2 ALLOWED PER 10000 IN ROOM AIR	PER MINUTE	PER HOUR
5.0	100.0	6000
5.5	66.6	4000
6.0	50.0	3000
6.5	40.0	2400
7.0	33.3	2000
7.33	30.0	1800
7.5	28.6	1714
8.0	25.0	1500
9.0	20.0	1200
10.0	16.6	1000
15.0	9.1	545
20.0	6.2	375
30.0	3.8	231

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In order to facilitate such calculations, Table 22 is presented. By this table, the number of cubic feet of air required per person per minute or per

TABLE 23—VOLUME OF AIR REQUIRED FOR GIVEN STANDARD OF PURITY

CUBIC FEET OF SPACE IN ROOM PER INDIVIDUAL	PROPORTION OF CARBONIC ACID IN 10000 PARTS OF AIR NOT TO BE EXCEEDED AT END OF AN HOUR						
	6	7	8	9	10	15	20
	CUBIC FEET OF AIR (4 TO 10000) TO BE SUPPLIED PER HOUR						
100	2900	1900	1400	1100	900	445	275
200	2800	1800	1300	1000	800	345	175
300	2700	1700	1200	900	700	245	75
400	2600	1600	1100	800	600	145	NONE
500	2500	1500	1000	700	500	45	
600	2400	1400	900	600	400	NONE	
700	2300	1300	800	500	300		
800	2200	1200	700	400	200		
900	2100	1100	600	300	100		
1000	2000	1000	500	200	NONE		
1500	1500	500	NONE	NONE			
2000	1000	NONE					
2500	500						

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hour may be obtained directly for various standards of purity. For instance, if there was permitted a proportion of 7.5 parts of carbon dioxide to 10,000 parts of air, 28.6 cu. ft. of air per minute per person or 1714 cu. ft. per hour would be required.

Work Problem No. 69

When the problem is presented in a somewhat different manner, Table 23 will be found useful. For instance, suppose the size of a room which is to be used as an assembly hall for a given number of people is known and it is desired to know how many cubic feet of air must be supplied per hour in order to maintain a desired purity.

Assume the volume of the room as 57,600 cu. ft. and that 200 people will occupy it. Dividing 57,600 by 200 the quotient is 282 cu. ft. per person. Calling this 300 and allowing 7 to 10,000 parts it is indicated by Table 23, that 1700 cu. ft. of air must be supplied per hour.

Work Problem No. 70

AIR REQUIRED FOR VENTILATION

Whenever possible, the air supply to any given room should be based upon the number of occupants. Unfortunately these data are not always available. Therefore the amount of air to be supplied per hour is often based upon the number of air changes considered good practice. Table No. 24 will serve as a guide in this connection. The

TABLE 24—NUMBER OF AIR CHANGES PER HOUR

USE OF ROOM	CHANGES OF AIR PER HOUR
PUBLIC WAITING ROOMS	8 TO 12
PUBLIC TOILETS	10 TO 20
COAT AND LOCKER ROOMS	8 TO 12
MUSEUMS	4 TO 5
OFFICES, PUBLIC	8 TO 12
OFFICES, PRIVATE	4 TO 5
DINING ROOMS, PUBLIC	8 TO 12
LIVING ROOMS	4 TO 5
LIBRARIES, PUBLIC	4 TO 6
LIBRARIES, PRIVATE	3 TO 4

TABLE 25—AIR CHANGES DUE TO NATURAL INFILTRATION WITH DIRECT HEATING SYSTEMS

TYPE OF BUILDING	NUMBER CHANGES PER HOUR
RESIDENCE	HALL 3 – SITTING ROOM, ETC. 2 – SLEEPING ROOM 2
STORE	FIRST FLOOR 2 TO 3 – SECOND FLOOR 1½ TO 2
OFFICE	FIRST FLOOR 2 TO 2½ – SECOND FLOOR 1½ TO 2
CHURCH & ASSEMBLY HALL	FROM ¾ TO 3
LARGE ROOM, SMALL EXPOSURE	FROM ½ TO 1

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TABLE 26—AIR REQUIRED FOR VENTILATION

TYPE OF BUILDING	CUBIC FEET OF AIR REQUIRED PER PERSON	
	PER MINUTE	PER HOUR
HOSPITALS, ORDINARY	42	2500
HOSPITALS, SURGICAL CASES	50	3000
HOSPITALS, CONTAGIOUS DISEASES	100	6000
SCHOOLS, ADULTS	40	2400
SCHOOLS, CHILDREN	30	1800
THEATRES	40	2400
CHURCHES	30	1800
PRISONS	30	1800
ASSEMBLY HALLS	30	1800
FACTORIES	33	2000
FACTORIES (UNHEALTHY TRADES)	59	3500

quantity of air required per person for various classes of service in good ventilation practice is given in Table 25, the data having been compiled from several sources. Unless otherwise stated the data in this table is to be used in problems where such data are needed.

HEAT LOSS BY VENTILATION

One B.T.U. will raise the temperature of 1 cu. ft. of air 55° at average temperatures and pressures;—or it will raise 55 cu. ft. through 1 degree. Therefore, if the number of cubic feet of air per hour required for ventilating purposes and the number of degrees through which it is to be warmed are known, to find the total required B.T.U. it is only necessary to multiply the quantity of air by the temperature rise and divide by 55. For instance suppose it is desired to determine the number of B.T.U. required per hour in zero weather for the ventilation of a church seating 400 people, inside temperature 70° F.

Total air required = 1800 (Table 26) × 400 = 720,000 cu. ft.

$$\text{B.T.U.} = \frac{720{,}000 \times 70}{55} = 916{,}000 \text{ B.T.U.}$$

Note that the rise in temperature and the 55 are constant so values may be established for the ratio $\frac{\text{Temp. rise}}{55}$. The following represent values most commonly used.

Thus:—

For 60° rise, 60 ÷ 55 = 1.09
For 65° rise, 65 ÷ 55 = 1.18
For 68° rise, 68 ÷ 55 = 1.24
For 70° rise, 70 ÷ 55 = 1.27
For 72° rise, 72 ÷ 55 = 1.31
For 80° rise, 80 ÷ 55 = 1.46

Work Problem No. 71

PART 1.

FUNDAMENTALS OF HEATING

LESSON 5.

Heating Requirement Estimates

HEATING REQUIREMENT ESTIMATES— EQUIVALENT TEMPERATURE GUARANTEES.

In all previous consideration of heat losses, it has been assumed that ceiling heights were not greater than 12 ft. The specified room temperature in the preceding discussion and assigned problems has referred to the temperature of the air as measured at the breathing line considered to be approximatley 5 ft. above the floor.

The temperature at this height has therefore been used as the average temperature of the air in contact with the walls, windows and other parts of the room or building through which heat therein is transmitted to adjoining space.

EFFECT OF CEILING HEIGHT ON TRANSMISSION LOSS

If heat losses are to be calculated for buildings where the ceiling height of rooms exceeds 12 ft., suitable corrections should be made for the average temperature of the air in contact with wall and other heat transmitting surfaces, the temperature of which will exceed that at 5 ft. or breathing level.

According to Reitschel, the average mean temperature in rooms with very high ceilings never exceeds 1.15 times the temperature, at the breathing level. He presents a formula whereby the mean temperature of any room with ceiling height exceeding 12 ft. may be determined. It may be applied as follows:

First: Subtract 10 from the ceiling height.

Second: Multiply result FIRST by 0.017.

Third: Add 1 to result SECOND.

Fourth: Multiply temperature at breathing line by result THIRD and obtain the average temperature of the air in contact with transmitting surfaces. Thus to determine the mean temperature in a room having a ceiling height of 16 ft. when the temperature of the air at the breathing line is 70° F. the above four-step form is applied as follows:

First: 16 ft. (ceiling height)—10 ft. = 6 ft.

Second: 6 ft. × 0.017 = 0.102

Third: 0.102 + 1 = 1.102

Fourth: 70 (temp.) × 1.102 = 77.14° F.

Work Problem No. 72

AUXILIARY SOURCES OF HEAT SUPPLY

In addition to the quantity of heat introduced into a room by one of the methods previously described, there are other sources which might be termed auxiliary sources of supply.

Persons give up bodily heat and where large groups assemble in one room, the total quantity of heat given off may amount to a relatively large part of that required per hour to maintain the desired inside temperature. Lights, motors and machinery also impart heat to the air of the room in which they are located.

Ordinarily, the quantity of heat emitted by persons, except in cases of assembly halls and theatres, is not sufficient to be taken into account when making heat requirement calculations. Nor should that from lights, motors and machinery be included as an auxiliary supply unless positive assurance is had that the quantity generated by such auxiliary sources will always be available when the required inside temperature is to be maintained. On the other hand, enough heat may be generated by machinery, etc., in a given room to supply more than is needed for the maintenance of a specified temperature within that room, thus necessitating that provision be made to remove instead of supply heat.

Motors and machinery which they drive when located in the same room, convert all the electrical energy supplied into heat. This heat is retained in the room unless the manufactured product is removed from the room with a temperature higher than that maintained in the room.

In the case where power is transmitted to the machinery from outside the room, then only the heat equivalent to the brake horsepower supplied is converted.

TABLE 27. HEAT EMITTED BY PERSONS, LIGHTS, MOTORS AND MACHINERY

OBJECT	CONDITION			B.T.U. PER HOUR EMITTED
PERSONS	AT REST			400
	AT WORK			500
	AT VIOLENT EXERCISE			650
LIGHTS	ELECTRIC LAMPS			THE PRODUCT OF WATTS PER HOUR × NUMBER OF LAMPS × 3.415
	GAS PER CU. FT.		PRODUCER GAS	150
			ILLUMINATING GAS	700
			NATURAL GAS	1000
			ALLOW FOR WELSBACH BURNER = 3 CU. FT. PER HOUR	
			ALLOW FOR FISH TAIL BURNER = 5 CU.FT. PER HOUR	
	B.T.U. EQUIVALENT TO 1 HORSEPOWER HOUR = 2546. THE PRODUCT OF HORSEPOWER OF MOTOR × 2546 DIVIDED BY EFFICIENCY OF MOTOR			
MACHINERY	THE PRODUCT OF THE DEVELOPED (BRAKE) HORSEPOWER × 2546			

Table 27 contains data, for stated conditions, by which the total heat emitted or developed by persons, lights, motors and machinery may be calculated for stated conditions. In high-powered mills, the heat from the motors and machinery is the

chief source of heating and frequently is sufficient to overheat the building, even in zero weather so that cooling by ventilation throughout the year is necessary.

Work Problems Nos. 73, 74 and 75

APPROXIMATE ESTIMATE OF HEATING PLANT SIZE AND FUEL REQUIREMENTS

The preparation of heating and ventilating designs, especially in connection with large buildings often requires that an estimate be made of the maximum and average demand for heat, together with an estimate of the amount of fuel required. It may also be desirable to prepare a load curve to show the quantity of fuel or heat-demand for each of the months of the heating season.

It is customary, as covered in preceding lessons, to base calculations for heat losses on an outside temperature of 0° F. and on inside temperature of 70° F. In many localities, zero weather may occur only in January or February and then only during the early morning hours and lasts for never more than three to four hours at a time. The maximum demand for heat thus obtains for very short periods so that during the greater part of the heating season, the actual demand for heat is relatively a small part of the total designed boiler capacity.

For large and important designs, a temperature fluctuation chart should be used. A chart of this kind should contain four curves, as shown on the typical chart illustrated in Fig. 10. The data required for preparing a temperature-fluctuation chart should be obtained from hourly weather bureau records taken at or near the locality in question, or by personal observation extending over a sufficiently long period or from reliable heating and power plants log records of a nearby station.

The scale on the left of the chart represents outdoor temperatures with a range of 0° F. (at top) to 70° F. (at bottom). Extending across the top are 24 equal divisions representing the 24 hours of a day.

The curve marked "coldest day" was prepared by plotting on each hour line, the temperature

existing at the time. For example, at 9 A. M., the temperature was 5° F. for locality for which this sample chart is prepared. In like manner, the curve for "coldest month" is obtained by averaging the temperatures at each respective hour for all

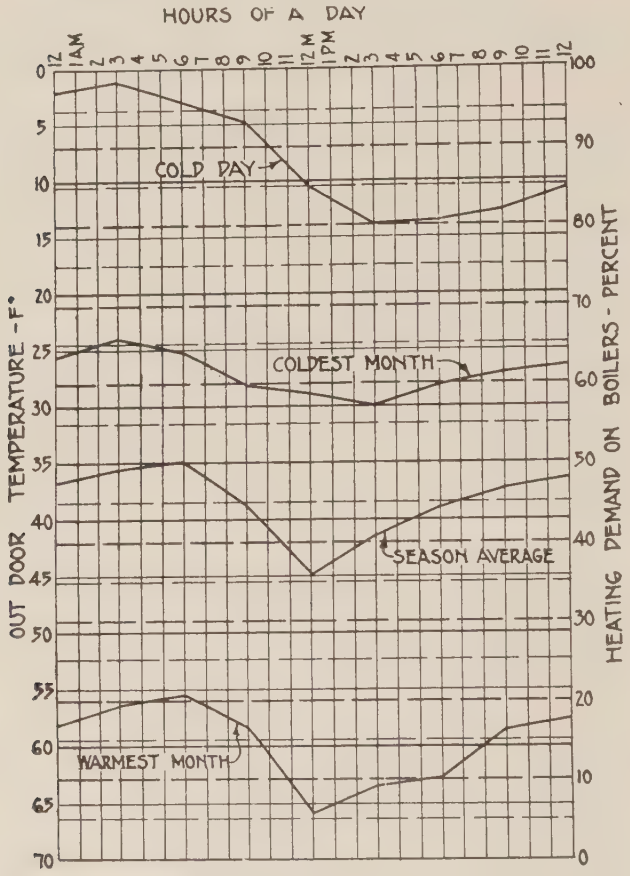

HOURS OF A DAY
12 1AM 2 3 4 5 6 7 8 9 10 11 12M 1PM 2 3 4 5 6 7 8 9 10 11 12
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
100 90 80 70 60 50 40 30 20 10 0
COLD DAY
COLDEST MONTH
SEASON AVERAGE
WARMEST MONTH
OUT DOOR TEMPERATURE - F°
HEATING DEMAND ON BOILERS - PERCENT

Fig. 10. Typical Temperature-Fluctuation Chart

days of the month and plotting these values as explained for the "cold day" curve; similarly for the "warmest month" curve. The "season average" curve is obtained by averaging all temperature readings for the same hour during the entire heating season.

The scale on the right of the chart is divided into 20 parts each of which represents 5%. By designing, for 0° F. temperature outside and 70° F.

inside, the total boiler capacity represents 100%. With the aid of the curves as plotted, the estimated percent of boiler capacity required at any time of the day may be read as follows:

Assuming that it is the coldest day for the locality at 3 P. M., it is noted that the "coldest day" curve, for this hour intersects the 80% line, showing that this percentage of the total boiler capacity will be required.

Work Problems Nos. 76 and 77

Temperature fluctuation charts may be prepared so as to show curves for each month of the heating season but it is not intended at this point in the course to do more than give the student a general idea of the use of such charts.

LOAD CURVE

Let it be assumed that the following represents average monthly temperatures for a given locality during the heating season:

	Temp. Deg.F. Out-side	In-side	Diff.	Average Heat. Demand
October	55	70	15	21.4%
November ..	42	70	28	40.0%
December ..	26	70	44	62.8%
January ...	21	70	49	70,0%
February ..	23	70	47	67.1%
March	35	70	35	50.0%
April	52	70	18	25.7%

Since the demand for heat will vary according to outside temperature changes, the percent of average heat demand per month may be found by dividing the difference between the inside and outside temperature by the inside temperature and multiplying by 100. Thus if the outside temperature is 0° F., and inside temperature 70° F., the difference is 70° F. which, divided by 70° (inside temperature) × 100, indicates the heat demand to be 100%; in the case of the month of January when the average outside temperature is 21° F. the difference is 49° F. and $(49 \div 70) \times 100 = 70.0\%$.

Similar values for the assumed monthly temperatures given above are tabulated in the last column.

These average heat-demand values for each month are used to prepare the load curve shown in Fig. 11. The horizontal divisions to represent months are made any convenient length, while the height of the curve for any month corresponds to the percent demand as developed above. For example, the height for October is 21.4%, the total height of the chart, while that for January is 70%. The average demand for the season may be indicated by averaging the percent heat-demands for all the months. In the selected example, this amounts to 48.14% and is indicated by the line so marked on the chart.

Thus far, the consideration of the load chart has been in general terms. To apply it to actual fuel requirements for a particular installation, it is necessary to consider local physical conditions which, if not known, may be assumed for the purpose of application. These include the total equivalent square feet of direct radiation in the building or for which heat is demanded, the total number of hours that the system will operate during a heating season and the kind and grade of fuel used.

ESTIMATING FUEL REQUIREMENTS PER HEATING SEASON

Knowing the factors mentioned in the last sentence, the total fuel required per heating season may be estimated so as to give a close approximation of what the fuel consumption should be under fair operating conditions. The following method may be used:

First: Note the total equivalent square feet of direct radiation required or installed, based on 0° F. outside and 70° F. inside.

Second: Multiply result FIRST by the number of hours per day that heat will be required.

Third: Multiply result SECOND by the number of days that heat will be required.

Fourth: Multiply result THIRD by the number of B.T.U. given off per hour by each square foot of direct radiation.

Fifth: Multiply result FOURTH by the average demand for season, (see Fig. 11, this may usually

be assumed at 50%), and obtain the total B.T.U. that will be given off by the entire system during a heating season.

Sixth: Multiply the heat value of the fuel used (B.T.U. per pound) by 2000 and obtain the total B.T.U. per ton of coal. (If oil is used, the heat value per pound or per gallon should be used and the constant 2000 omitted.)

Seventh: Assume an overall boiler efficiency (usually 65%) and multiply SIXTH by this factor to obtain the net B.T.U. per ton for coal (or per pound or per gallon for oil), imparted to the heating medium.

Eighth: Divide result FIFTH by result SEVENTH and obtain the total tons of coal required per heating season; or the total pounds or gallons of oil.

The eight-step form is applied as follows for the following conditions:

Total equivalent square feet of direct radiation =3258.

Hours per day heat is required = 24.

Days per heating season=240.

B.T.U. given off per square foot of radiation per hour=250.

Average demand for season = 50%.

Heat value of coal = 13250 B.T.U. per pound.

Efficiency of plant = 65%.

APPLICATION OF EIGHT-STEP FORM

First: 3258 sq. ft.

Second: 3258 (sq. ft.) x 24 (hrs. per day) = 78,192

Third: 78,192 x 240 (days) = 18,765,080

Fourth: 18,765,080 x 250 = 4,691,270,000

Fifth: 4,691,270,000 x 0.50 = 2,345,635,000

Sixth: 13,250 x 2000 = 26,500,000

Seventh: 26,500,000 x 0.65 = 17,225,000

Eighth: 2,345,635,000 ÷ 17,225,000 = 136 plus tons.

Work Problems Nos. 78 and 79

MONTHLY REQUIREMENTS BY LOAD CHART

In order that the monthly fuel requirements for a particular installation may be closely approximated, the load chart should be amplified to show

the percent of the season's fuel demands that will be required each month during the heating season. These are indicated by the percentages noted in the lower part of the cross-hatched part of the chart, the values being obtained by adding the heat demand percentages for all months and dividing each

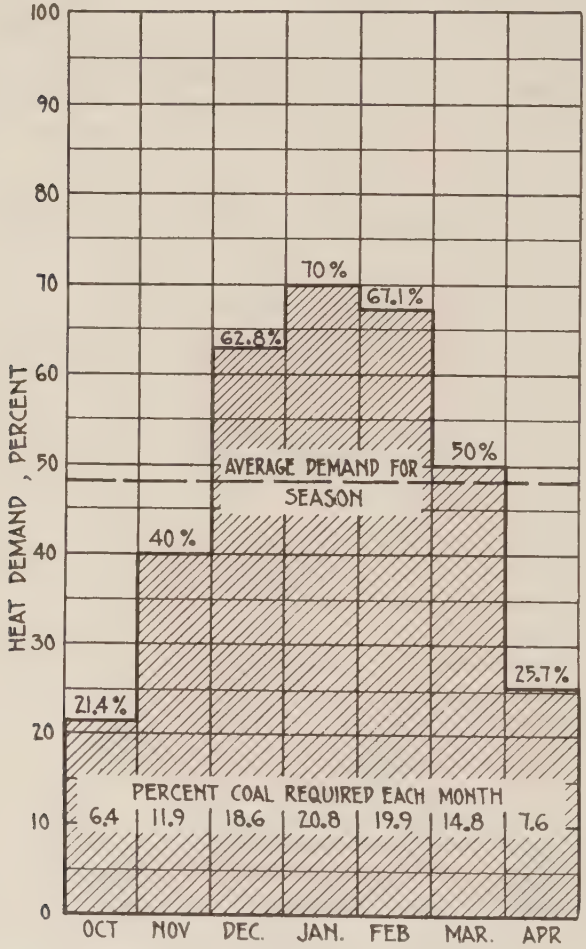


Fig. 11. Typical Load Chart

respective monthly demand by the sum of all and multiplying by 100 to express it as a percentage. Thus the total of all demands is 21.4 plus 40.0 plus 62.8 plus 70.0 plus 67.1 plus 50.0 plus 25.7=337.0 and the percent fuel required for October is (21.4÷

337.0)×100=6.4%. In like manner, the percentages as noted for the other months are obtained.

With such a chart prepared for a particular installation, a ready means of checking the monthly consumption of fuel is available and by comparing the monthly temperatures with those representing average conditions, leaks may be detected and correction methods applied before accumulated losses have become exceedingly large.

So, if the season fuel requirements for a particular installation are determined to be 136 tons, and the January temperatures represent average conditions, the consumption of coal to be expected during this month would be 136 (tons) × 0.208 = 28.3 tons for a locality to which the load chart of Fig. 11 was applicable.

Work Problem No. 80

ESTIMATING BOILER CAPACITY (APPROXIMATE)

In the preceding discussion, it has been assumed that the heating system has been designed or is in operation. Estimates of probable boiler capacity are often desired before going to the expense of preparing a complete heating design.

Such an approximate estimate may be made from the architect's preliminary plans in terms of the probable transmission losses as follows:

First: Multiply total exposed wall surface in square feet by 21 and obtain heat units lost per hour through the wall.

Second: Multiply total area of window openings in square feet by 70 and obtain heat units lost per hour through the glass.

Third: Multiply total lineal feet of window and door openings by 72 for ordinary construction (use 31 for metallic stripped sashes) and obtain the heat units required per hour to care for infiltration.

Fourth: Add results, FIRST, SECOND, THIRD and add 15% of this total for line losses.

Fifth: Divide result FOURTH by 30,000 and obtain the boiler horse power per hour necessary to meet the most severe weather conditions (assume 0° F. outside and 70° F. inside).

Sixth: Refer to a temperature-fluctuation chart for the locality in question from which the average percent heating demand on boilers may be determined for the season or during the coldest, or warmest month.

Work Problem No. 81

FUEL REQUIREMENTS BASED ON APPROXIMATE BOILER CAPACITY

Fuel requirements may be based on a preliminary boiler estimate by dividing the result obtained under FOURTH in the six-step form directly above by 250, representing the number of heat units given off by every square foot of direct radiation. Thus an approximate figure is obtained for the total equivalent square feet of radiation required.

With the square feet of equivalent direct radiation known, procedure is as explained by the eight-step form given under "Estimating Fuel Requirements per Heating Season."

Work Problems Nos. 82 and 83

EQUIVALENT TEMPERATURE GUARANTEES

Practically all heating contracts contain a clause guaranteeing specified inside temperatures for a given outside temperature. Tests of the system to determine how well it will fulfill its requirements must often, if not usually, be made when the outside temperature differs from that stated in the contract.

This makes it necessary to compare temperatures obtained under test conditions with those as given in the guarantee clause.

The actual inside temperature to be maintained by a heating system for other than the inside and outside temperatures named in the contract may be obtained in the following manner:

First: Multiply the guaranteed inside temperature by the actual outside temperature during the test.

Second: Add the actual outside temperature to the guaranteed inside temperature.

Third: From result SECOND, subtract the outside temperature stated in the guarantee.

Fourth: Multiply result THIRD by the temperature of the heating medium within the radiator.

Fifth: From result FOURTH, subtract result FIRST.

Sixth: From the temperature of the heating medium within the radiator, subtract the outside temperature stated in the guarantee.

Seventh: Divide result FIFTH by result SIXTH and obtain the actual inside temperature required under test conditions.

APPLICATION OF EQUIVALENT TEMPERATURE GUARANTEE FORM

The above form may be applied for a selected example as follows: A contract requires that a heating system shall be capable of maintaining the inside temperature at 70° F. when the outside temperature is 0° F. and steam is supplied the radiators at a pressure of 5 lbs. per square inch (temperature of steam at this pressure is 227° F.).

Required: The inside temperature to be maintained with the system tested when the outside temperature is 30° F.

First: 70 (guar. inside) $\times$ 30 (test out.) = 2100.
Second: 30 (test out.) + 70 (guar. inside) = 100.
Third: 100 — 0 (guar. out.) = 100.
Fourth: 100 $\times$ 227 (temp. steam) = 22,700.
Fifth: 22,700 — 2100 = 20,600.
Sixth: 227 (temp. steam) — 0 (guar. outside) = 227.
Seventh: 20,600 $\div$ 227 = 90.9° F.

Work Problems Nos. 84, 85 and 86

PART H.

HOT WATER HEATING

LESSON 1.

Operating Principles

GRAVITY
HOT WATER HEATING.
OPERATING PRINCIPLE.

In Fig. H-1-1 is shown a simple open-type system with gravity circulation. Before considering how such a system operates, a clear understanding should be had of the simple laws which govern the movement of heated water through the parts of such a system, otherwise proper circulation of water will not be assured.

An open, gravity-type water heating system consists essentially of four parts: (1) the boiler for continually heating the water, (2) the piping for conducting the water from and to the boiler, (3) the radiators for holding temporarily a given quantity of water until it has given up a definite part of its heat, and (4) an expansion tank for providing storage space for the increased water volume caused by its expansion due to increase in temperature.

When there is no fire in the boiler, the system is said to be cold. The boiler, piping and radiators are filled with water at practically the same temperature. The expansion tank is partly filled. The water in the entire system is practically motionless.

The duty of the water is to convey heat from the boiler to the radiators from which it is imparted to the air of the rooms. To perform this duty the water must be set in motion and to perform it continuously the water must be kept in motion. There is practically no loss of water during operation within desirable working limits. The water is merely the carrier of the heat.

Every gravity-circulating system, regardless of how many pipes and radiators it may embody, may be reduced essentially to two columns of water, one designated as the ascending column and the other as the descending column. The ascending column, in a down-feed system (see Fig. H-1-1), consists of the boiler, supply piping and part of the water in the expansion tank, while the descending column consists of the radiator, return piping and part of the water in the expansion tank.

When a fire is started in the heater, the temperature of the water therein is raised. The water expands, its unit volume becomes lighter in weight and causes an ascending movement of the water in the supply piping. This difference in weight between a given volume of water in the ascending column and an equal volume in the descending column results in the establishment of a condition of unbalanced static pressure in the system. The rising of the lighter and warmer water in the ascending column and the falling of the cooler and heavier water in the descending column to be re-heated in the boiler and re-circulated assures the continuance of operation so long as a fire is maintained in the heater.

Work Problem H-1-1

SYSTEMS OF WATER HEATING

The principle of heating by the circulation of heated water through a system of pipes and radiators may be applied in several ways and modifications of the different classified systems is not un-

usual. While this course presents the essential characteristics of the different systems of water heating it should not be presumed that every modification or combination of such systems is covered. With a clear conception of the principles as explained and applied throughout this work, the student should be able to plan and design a water

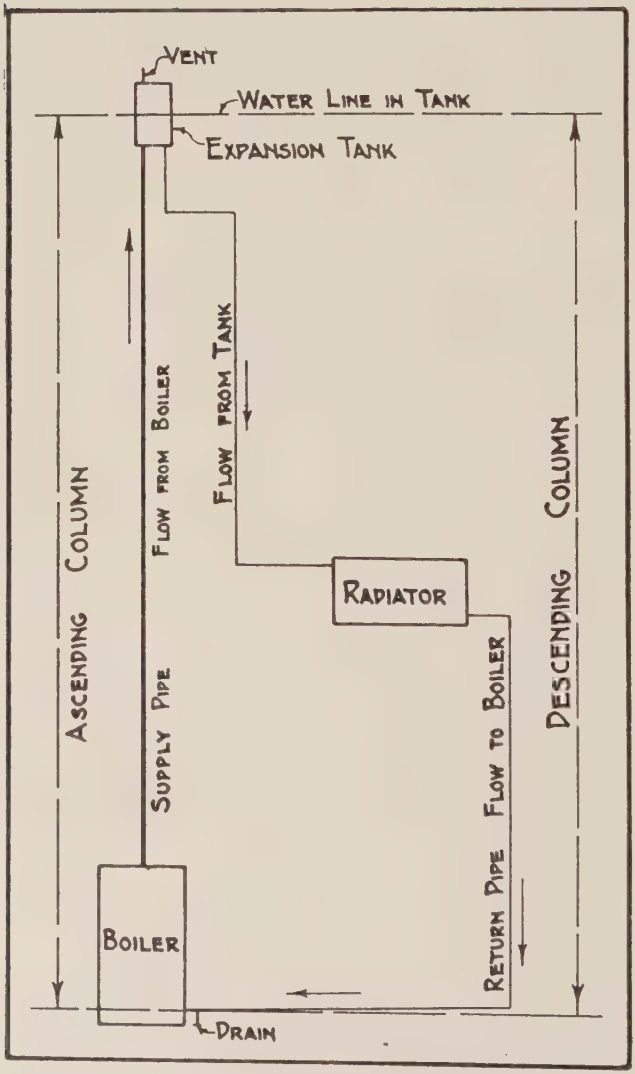


Fig. H-1-1. Typical Gravity Water Circulating System

heating system suited to given requirements or recommend, with assurance, advisable changes to existing systems that do not function properly.

In general, gravity water heating systems may be classed as follows:

One-pipe up-feed system.
Two-pipe up-feed system.
Two-pipe down-feed, single riser system.
Two-pipe down-feed, double riser system.
One-pipe circuit system.

Each of these systems and the application thereof will be covered in detail as we progress. A discussion of radiators and radiation is dealt with separately. It will be assumed in the discussion of the different water systems that the required radiation has been calculated and it will be stated wherever needed, either in the explanation of a certain system or for an assigned gravity water heating design problem.

PIPE SIZING.

Previous to a consideration of the different types of systems of water heating, it is essential that the student be able to proportion pipe runs generally, according to the carrying capacity of the pipes of which a run consists. Two methods will be presented.

SIZING PIPES—METHOD 1.

The carrying capacity of pipes is governed by diameter and, consequently, area; internal frictional resistance which varies directly as the area; and the condition of the interior surface of the pipe. The problem is usually presented as follows:

To find the size of pipe required to serve a number of smaller pipes of the same or different diameters.

Refer to Table H-1-1, which contains equivalent pipe data. In this table, the carrying capacity of each size pipe listed is, in turn, taken as unity and the equivalents for each size larger are expressed for diameters up to 8 in. Thus a pipe of 1-in. diameter is equivalent to 4.88 pipes of ½-in. diameter (by line A); or (by line H), a pipe of 4-in. diameter will supply 2.12 pipes of 3-in. diameter.

Thus, this table affords a convenient means for determining, with reasonable practicality, the size of pipe required for serving a number of smaller pipes, or conversely, the number of pipes of a given size that may be supplied by a single pipe of a given diameter.

Work Problems H-1-2; H-1-3

TABLE H-1-1
EQUIVALENT PIPE DATA

REFERENCE	NOMINAL DIAMETER – INCHES												
	½	¾	1	1¼	1½	2	2½	3	3½	4	5	6	8
A	1.00	2.27	4.88	10.0	15.8	31.7	52.9	96.9	140	205	377	620	1292
B		1.00	2.05	4.30	6.97	14.0	23.3	42.5	65	90	166	273	569
C			1.00	2.25	3.45	6.82	11.4	20.9	30	44	81	133	278
D				1.00	1.50	2.70	5.25	9.1	12	19	32	68	110
E					1.00	1.26	3.34	6.13	9	13	23	39	82
F						1.00	1.67	3.06	4.5	6.5	11.9	19.6	40
G							1.00	1.82	2.70	3.87	7.12	11.7	24
H								1.00	1.50	2.12	3.89	6.39	13.3
I									1.00	1.25	2.50	4.25	9.0
J										1.00	1.84	3.02	6.3
K											1.00	1.65	3.4
L												1.00	2.1
M													1.00

TABLE H-1-2
EQUIVALENT PIPE FACTORS

NOMINAL DIAMETER IN INS.	FACTOR
½	2
¾	5
1	10
1¼	20
1½	30
2	60
2½	110
3	175
3½	260
4	380
5	650
6	1050
7	1600
8	2250

Figure H-1-2 represents a run of piping from A to F from which five branches are taken off at points B, C, D, E and F, respectively. The sizes of each branch are as follows:

Branch B, 2 in. diameter
C, 2½ in. diameter
D, 1½ in. diameter
E, 1¼ in. diameter
F, 1 in. diameter.

Disregarding the length of the run at this stage of the work and thereby assuming that the effect of length on operation is negligible (length of run may have a decided effect on operation and this will be discussed later in the course), we will proceed to determine the size of the different sections of the run, namely, EF, DE, CD, BC and AB.

The section EF supplies only the last branch, a 1-in. diameter pipe. By Table H-1-1, a pipe of 1-in. diameter is equivalent to 4.88 pipes of ½-in. diameter. So, in terms of pipes of ½-in. diameter, section EF is equal to 4.88.

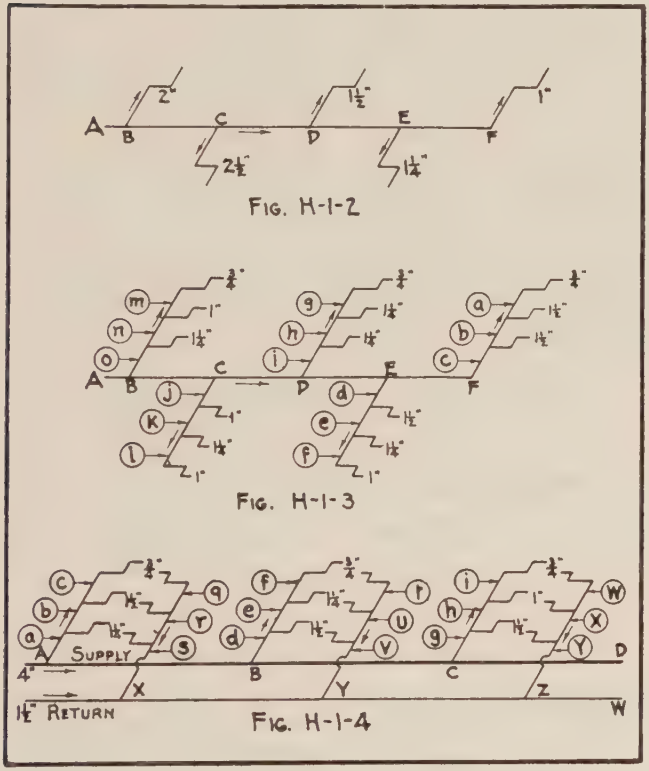


Fig. H-1-2. Single Pipe Run with Single Branches
Fig. H-1-3. Single Pipe Run with Multiple Branches
Fig. H-1-4. Supply and Return Pipe Run with Multiple Branches

The branch entering at E is of 1¼-in. diameter. By Table H-1-1, this is equivalent to 10.00 pipes of ½-in. diameter. Therefore section DE must be equivalent to 4.88 + 10.00 = 14.88 pipes of ½-in. diameter. Line A, Table H-1-1, indicates that a pipe of 1½-in. diameter is equivalent to 15.8 pipes of ½-in. diameter, therefore section DE should have a diameter of 1½-in.

Section CD supplies section DE and in addition, the branch from D. Its equivalent in ½-in pipes must be equal to that for section DE + that for the branch from D or 14.88 + 15.8 = 30.68 pipes of ½-in. diameter; therefore, section CD should have a diameter of 2-in. (line A, Table H-1-1).

The size of section BC is determined similarly by adding the equivalent of the branch at C. Thus 30.68 + 52.9 = 83.58 pipes of ½-in. diameter; therefore, section BC should have a diameter of 3 in.

Similarly, 31.7 is added for the branch from B and section AB is equivalent to 83.58 + 31.7 = 115.28 pipes of ½-in. diameter, indicating that section AB should have a diameter of 3½ in.

Summarized, the diameters of the sections are as follows:

Section AB — 3½ in. diameter
BC — 3 in. diameter
CD — 2 in. diameter
DE — 1½ in. diameter.
EF — 1 in. diameter.

Work Problem H-1-4

SIZING PIPES—METHOD 2

Table H-1-2, which contains pipe factors, may be used in a manner similar to Table H-1-1 for the same purpose. By some, it is considered somewhat more convenient. In assigned problems, the student may use either table unless otherwise instructed.

Section CD must be capable of supplying one 1-in. branch, one 1¼-in. branch and one 1½ in. branch. Its factor is found as follows:

One 1-in. branch = 1 x 10 (factor from table H-1-2) = 10
One 1¼-in. branch = 1 x 20 (factor from table H-1-2) = 20
One 1½-in. branch = 1 x 30 (factor from table H-1-2) = 30

Factor for section CD = 60

Therefore CD should be 2 in. in diameter.

In a similar manner, the required diameter for section AB is found as follows:

One 1-in. branch	= 1 x 10 (factor from table H-1-2)	= 10
One 1¼-in. branch	= 1 x 20 (factor from table H-1-2)	= 20
One 1½-in. branch	= 1 x 30 (factor from table H-1-2)	= 30
One 2½-in. branch	= 1 x 110 (factor from table H-1-2)	= 110
One 2-in. branch	= 1 x 60 (factor from table H-1-2)	= 60
	Factor for section AB	= 230

Therefore AB should be 3½ in. in diameter.

Work Problem H-1-5

GENERAL CONSIDERATIONS AFFECTING THE DESIGN OF WATER HEATING SYSTEMS

Before considering the different arrangements of piping for the various types of water heating systems in detail, there are certain essentials with which the student should be familiar.

Figure H-1-5 shows a typical layout for a two-pipe, up-feed open-tank water heating system having eight radiators. The arrows indicate the direction of flow. Several arrangements of piping to and from the radiators are indicated. The supply main M and return main N are supposed to extend to supply other radiators.

Work Problem H-1-6

The size of each radiator valve and of the piping for the entire system is governed mainly, (1) by the area of heating surface of the radiator, invariably expressed in square feet, (2) the method by which water is conveyed to and from the radiator, (3) the height of the radiator above and its distance from the boiler, and (4) as to whether it is a direct or indirect radiator.

The type of system is very important and it is most essential that requirements and conditions be fully understood before proceeding with actual design work. For the time being, it will be assumed that references are made to an open-tank heating system. It may be mentioned in passing that in a closed-tank system the water circulates much faster than through an open-tank system and this

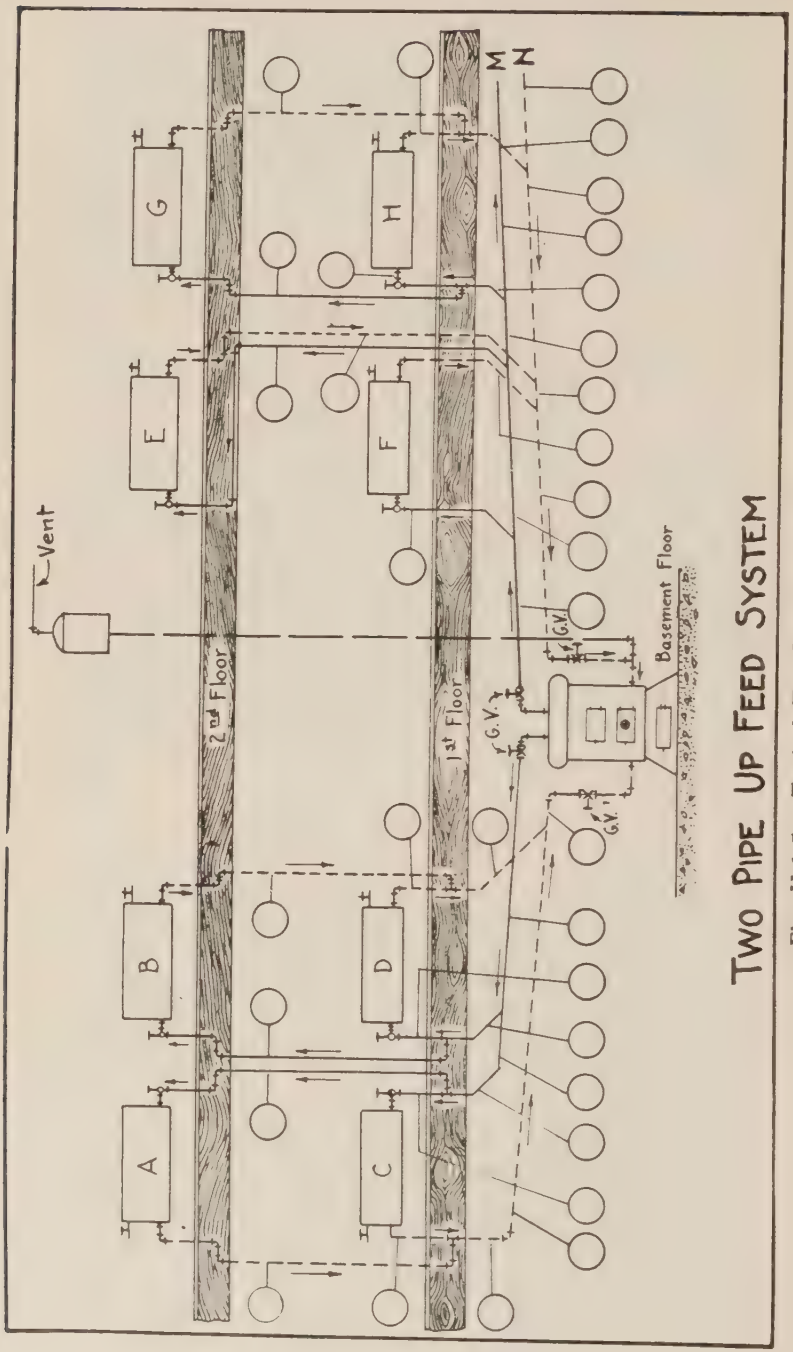


Fig. H-1-5. Typical Two-Pipe Up-Feed System

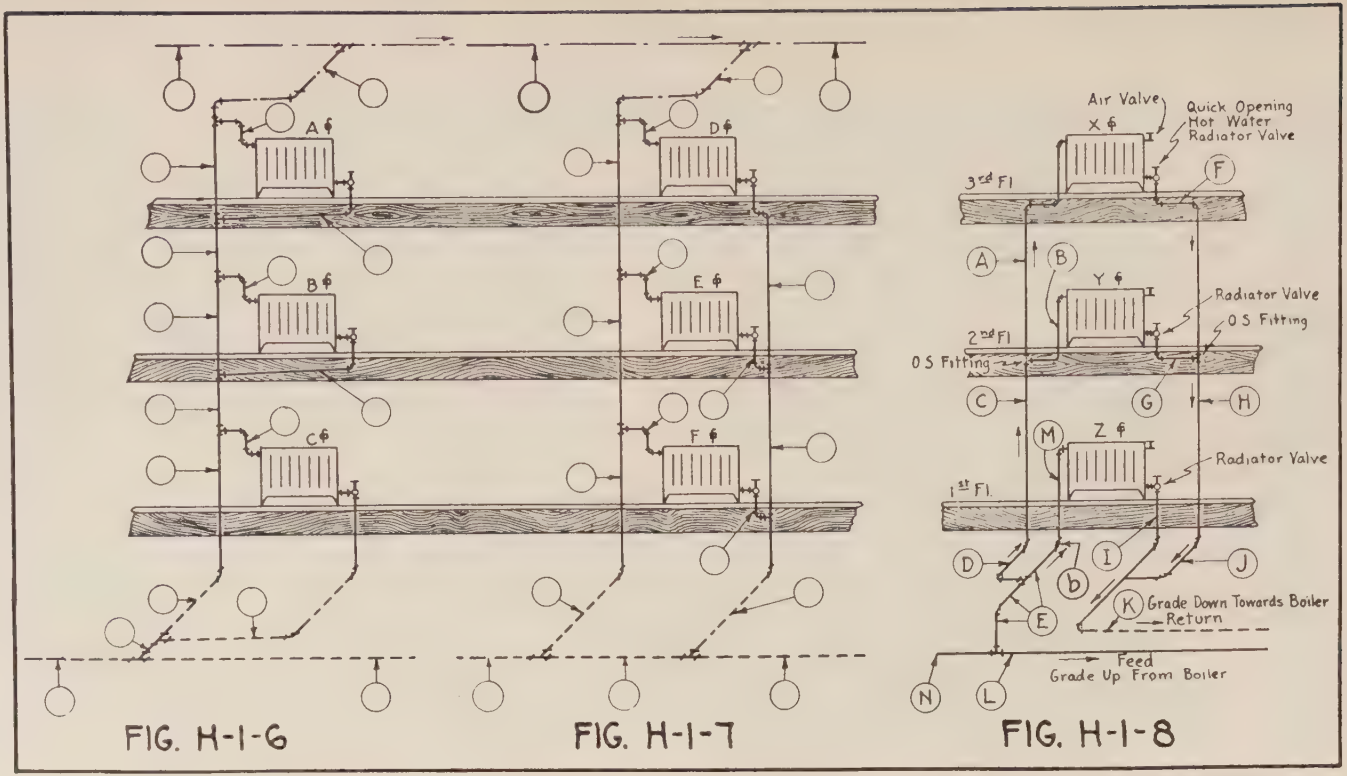


Fig. H-1-6. Typical Radiator Group, Down-Feed with Single Return.

Fig. H-1-7. Typical Radiator Group, Two-Pipe Down-Feed System.

Fig. H-1-8. Typical Radiator Group, Two-Pipe Up-Feed System.

requires the use of comparatively larger radiator valve areas, on open than on closed systems for radiators of the same size, similarly located.

Work Problem H-1-7

Furthermore, heated water has a tendency to flow quickly to the highest point of a heating system. Therefore, a pipe or valve of given size or area will supply a greater amount of radiation located on the second than on the first floor and a greater amount to a third-floor radiator than to one on the second floor. All these facts should be considered in order to design an efficient gravity water heating system.

Much judgment on the part of the designer is required in planning and proportioning mains, risers and branches for gravity water heating systems, regardless of the type of system employed. It is impossible in any written work on this subject to cover all conditions of detail design and installation. A complete presentation of the fundamentals and a mastering of them by the student is an absolute necessity if he would be prepared to avoid many of the pitfalls so often encountered in a more or less costly manner.

Gravity water heating systems may easily be thrown out of balance. This condition exists when radiators near the boiler get very hot water and the returns therefrom are correspondingly warmer than others farther along in the system. It, therefore, should be impressed upon the mind of him who would perform work that begets work, that a perfectly functioning job, especially, if the installation is larger than the ordinary residential plant, requires expert and careful designing in order to avoid short-circuiting and sluggish circulation. To maintain correct balance, every unit in the system must be capable of performing its independent function properly and of contributing its part toward correct balance of the entire system.

It is not unusual, indeed, it is frequently the case in gravity water heating systems that the return water from the first radiator supplied is the first to reach the boiler for re-heating and re-circulating, while that from the last radiator is the last to

return. This condition usually causes sluggish circulation and thus uneven heating of the radiators. It should be guarded against.

PIPING RADIATOR GROUPS

Figure H-1-8, shows a group of radiators for first, second and third floor piped for a two-pipe up-feed gravity water heating-system. Figure H-1-9 shows a basement plan for such a system with the radiator runs extending from the risers so as to permit clear presentation of the respective pipe sizes. Radiators on the different floors are designated by letters.

Figure H-1-9, shows the installation piped as a "reversed" return run, that is, the first radiator group supplied (A, B, C), is the one most distant from the boiler on the return side. This is preferable to a "direct" return (as mentioned above) in which the water first circulates through the radiators nearest the boiler and then through each succeeding group in turn, with the result that the ends of the main are slow in warming up; the last radiator may be "cold" and unsatisfactory operation result.

The piping runs shown in Figure H-1-9 make one complete circuit with mains pitching in opposite directions and consequently with water flowing in opposite directions. This is a very satisfactory method of piping a gravity water heating system, especially for buildings that are approximately square. The flow and return pipes are run close to the basement ceiling; the flow grades up from the boiler and the return grades down towards it. The slope should be not less than $\frac{3}{4}$ in. in every 10 ft. for both supply and return lines.

Work Problems H-1-8; H-1-9

TYPICAL REVERSED RETURN LAYOUTS

Figures H-1-10, H-1-11 and H-1-12 show three typical "reversed" return layouts. The radiators on the first floor are shown dotted. The supply is shown as a fairly broad solid line, the return as a solid line somewhat narrower. The supply main is

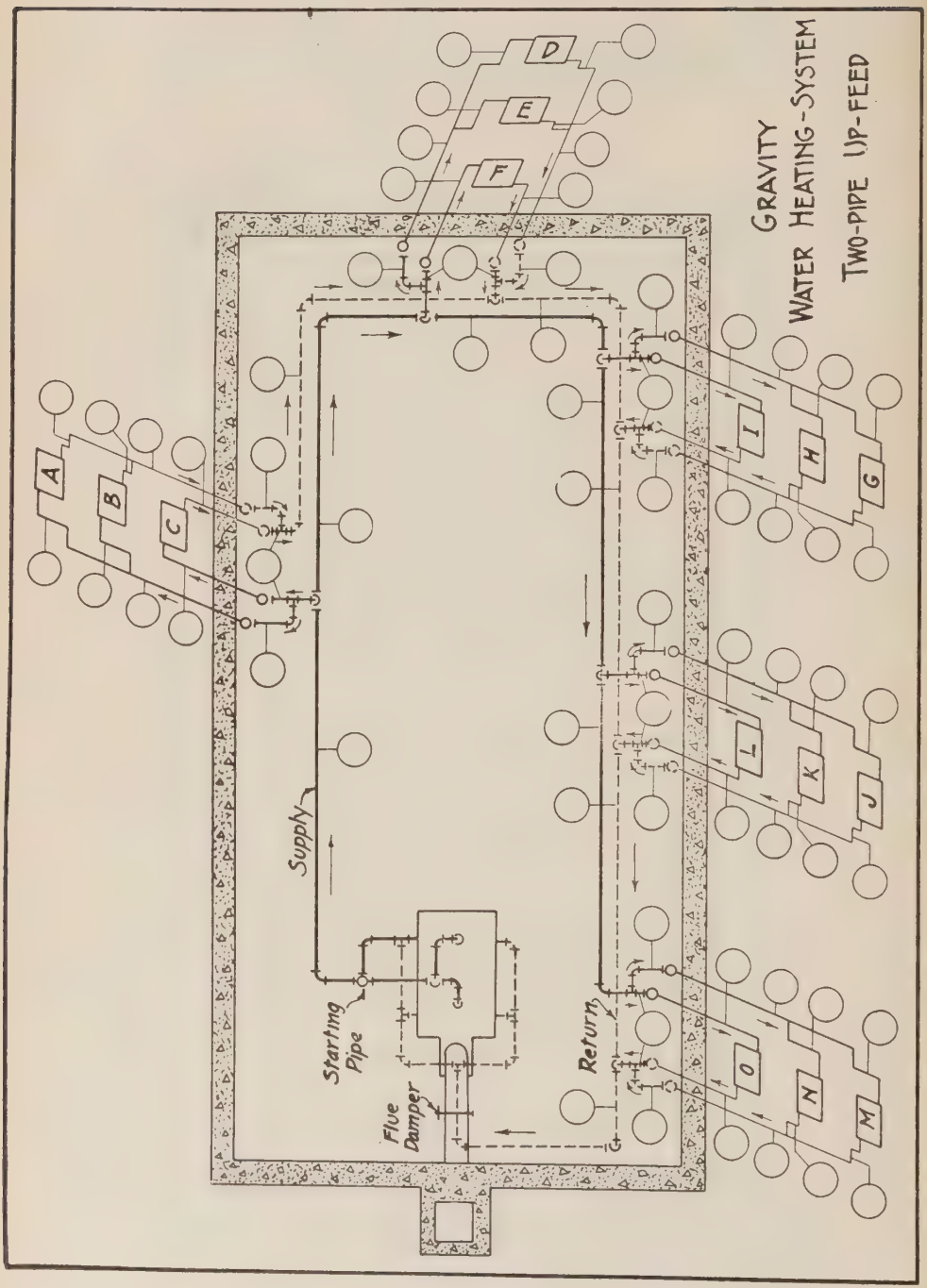


Fig. H-1-9. Basement Plan for a Two-Pipe Up-Feed Gravity Water Heating System

Fig. H-1-10. Simple Reversed Return, Two-Pipe Up-Feed Circuit System.

Fig. H-1-11. Equally Divided Supply and Reversed Return Two-Pipe Up-Feed System.

Fig. H-1-12. Unequally Divided Supply and Reversed Return Two-Pipe Up-Feed System

pitched upward from the heater with the high point at the last radiator take-off and low point where it leaves the heater.

Figure H-1-10 shows the simplest layout consisting of a circuit system with continuous return line. Fig. H-1-11 shows an equally-divided or two-circuit system with two reversed returns. The two sides of the main that extend from the point K should be balanced as to radiation supplied if 90° ells are used at the branch turns. When radiation supplied by two branches is not exactly but nearly equal for the two sides, the branch mains may be made the same size and the side carrying the slightly greater amount of radiation may be favored by setting the T-branch so as to rise with a 45° ell as indicated in Fig. H-1-11 where the right-hand branch supplies five radiators while the left-hand branch supplies six radiators, all assumed to have equal radiating surface.

Work Problems H-1-10 and H-1-11

Fig. H-1-12 shows a circuit somewhat similar to that of Fig. H-1-11 but with the supply main divided nearer the boiler. Thus, there is one short circuit that supplies the radiators nearest the boiler and a longer circuit that supplies the balance of the radiators. An arrangement like this may often be used with excellent results when radiators nearest the boiler are on the cold side of the building. In designing such a system, special care must be observed to obtain balance. The longer main may require that one size larger pipe be used than the calculations indicate and it may be advisable to favor circulation to it by taking off the branch with a 45° ell turned up as noted at N, Fig. H-1-12. Another solution might be to reduce the size of the smaller main by a pipe size and turn upward the ell that feeds it, so as to take this branch practically off the top of the main. An uneven divided supply like this has its limitations so if the job is large, it is decidedly better to use a center main as shown in Fig. H-1-11.

Work Problem H-1-12

This unequal divided supply also contains the "reversed" return feature for in each case the first radiator supplied is the last to have its return reach the boiler while the water to the last radiator supplied is the first to return. The length of water travel from the boiler to the radiator and back to the boiler should be as near equal for each of the different groups of radiators as it is possible practically to design and install the piping. In this manner, resistance to be overcome is practically the same for each group of radiators, irrespective of the distance of each group from the boiler. It should be noted that the return water starts at the first radiator served and flows in the *same* direction as the supply water, the main being increased in size as additional returns enter while the supply main is decreased in a similar manner after it has fed additional radiators.

Although omitted from Figures H-1-10, H-1-11 and H-1-12, for the sake of clearness, each supply and return connection at the boiler preferably should be provided with a valve and an expansion tank should be included. The line from the boiler to the expansion tank should contain no valve or any obstruction that might or could interfere with circulation thereto.

Work Problem H-1-13

DETERMINING RADIATOR VALVE AND PIPE SIZES FOR A GROUP OF RADIATORS

While tables are available by which pipe and radiator valve sizes, branch and main sizes may be specified and tables for this purpose are given in this course, a note of warning should be sounded with respect to the arbitrary use of them lest the student get the impression that they may be used as one uses a yardstick. Judgment cannot be entirely eliminated. A hard and fast rule for tables of capacities cannot be presented. Exceptions and modifications are frequently necessary. Such tables, however, are very useful in simplifying

design work and when viewed as a means to an end have a very definite and proper place in heating design work.

Four tables are included that have been collected from different sources. Where the authority is omitted, it is not known, the data being taken from the data files of the author.

TABLE H-1-3 GRAVITY WATER HEATING - SYSTEM

TWO-PIPE UP-FEED OPEN TYPE SYSTEM

PIPE SIZES IN TERMS OF RADIATION

MAINS		
PIPE SIZE INS.	DIRECT RADIATION SQ. FT.	INDIRECT RADIATION SQ. FT.
1¼	135	100
1½	220	135
2	350	225
2½	460	320
3	675	500
3½	850	650
4	1100	850
4½	1350	1050
5	1700	1350
6	3600	2900
7	4800	3900
8	6200	5000
9	7700	6300
10	9800	7900
12	14000	11400

NOTE:- LENGTH OF MAIN MUST BE MEASURED BACK TO BOILER. FOR MAINS OVER 100' MUST REDUCE CAPACITY IN RATIO OF $\sqrt{100 \div L}$

TABLES BY J.J. HOGAN

AUTHOR OF TABLES RECOMMENDS THEIR USE FOR ONE AND TWO PIPE WORK.

BRANCHES AND RISERS				
	FLOOR			
PIPE SIZE INS.	FIRST	SECOND	THIRD	FOURTH
	DIRECT RADIATION - SQ. FT.			
¾	30	45	55	70
1	60	75	85	95
1¼	110	120	135	150
1½	180	195	210	230
2	290	320	350	370
2½	400	490	525	550
3	620	650	690	730
3½	820	870	920	970
4	1050	1120	1185	1250
4½	1325	1400	1485	1560

NOTE:- FIRST FLOOR SUPPLY RISER CONNECTIONS SHOULD BE TAKEN FROM TOP OF MAIN AND RISERS. ABOVE FIRST AT 45°. ALL RETURNS INTO SIDE OF MAIN, (OR BOTTOM).

HARDING & WILLARD

Sizes of valves and piping obtained from one table for radiators of given area and location will likely vary slightly with those taken from another but practice and application will enable the student to select or possibly adopt one table in preference to another.

Throughout this work, for the sake of uniformity, the table which is to be used in each assigned problem will be stated and where necessary the modifications will be given.

TABLE H-1-4 GRAVITY WATER HEATING - SYSTEM

BALANCED OPEN TYPE SYSTEM

PIPE CAPACITIES IN SQUARE FEET OF RADIATION

PIPE SIZE INS.	RADIATORS			RISERS		MAINS	
	1ST FLOOR	2ND FLOOR	3RD FLOOR	2ND FLOOR	3RD FLOOR	LONG	SHORT
¾	40	55	70	60	90		
1	60	85	120	110	140		
1¼	100	130	160	170	200		
1½	150	190	250	225	300		200
2	250	300	400	450	600	200	450
2½				600	900	450	700
3						700	950
3½						950	1300
4						1300	2000
5						2000	3000
6						3000	4000
7						4000	6000
8						6000	8500

TABLE H-1-5 GRAVITY WATER SYSTEM.

PIPE SIZES

OPEN-TANK UP-FEED SYSTEM

RADIATOR LOCATION	DIRECT RADIATION SQ. FT.	SIZE OF TAPPING
FIRST FLOOR	25 or Less	¾ Inch
	26 to 50	1 "
	51 to 85	1¼ "
	86 to 125	1½ "
SECOND FLOOR	40 or Less	¾ "
	41 to 60	1 "
	61 to 100	1¼ "
	101 to 175	1½ "
THIRD FLOOR (AND ABOVE)	50 or Less	¾ "
	51 to 80	1 "
	81 to 125	1¼ "
	126 and Above	1½ "

In cases of extreme exposure or under conditions where circulation to and from it may be difficult, one size larger valve than ordinarily called for should be used. It is good practice to increase the valve size for a first floor radiator when it is the last connected radiator and is at the end of a main.

TABLE H-1-6.

FLOOR	DIRECT RAD.	PIPE SIZE
1ST	50	¾"
	100	1"
	200	1¼"
2ND	100	¾"
	200	1"
3RD	ALL	¾"

Referring to Fig. H-1-8 and using Table H-1-3, the pipes are proportioned as follows:

Size of Radiators

Third floor—radiator X—90 sq. ft.
Second floor—radiator Y—65 sq. ft.
First floor—radiator Z—50 sq. ft.

First: Use table (H-1-3 in this case) and read sizes of radiator valves.

For X, use 1¼ in.
Y, use 1 in.
Z, use 1 in.

Second: Use Table (H-1-3 in this case) and determine sizes of supply branches to each radiator.

For X, make pipe A 1¼ in.
Y, make pipe B 1 in.
Z, make pipe M 1 in.

Third: Determine sizes of return branches to each radiator. For the two-pipe up-feed system these are made the same as the supply, so make pipes,

F = 1¼ in.; G = 1 in.; I = 1 in.

Fourth: Determine size of risers that supply more than one radiator. Pipe C, for example, is a riser supplying radiators X and Y. Use Table H-1-2.

Factor for pipe A (1¼ in.) = 20
Factor for pipe B (1 in.) = 10
Factor for pipe C = 30; Use 1½-in. pipe.

Fifth: Determine size of branch from main. The pipe supplying the first-floor radiator is run full size over to the heel (point b, Fig. H-1-8) in order to favor the lowest radiator. Assume all radiation located on first floor, thus 90 + 65 + 50 = 205 sq. ft. will require a 2-in. pipe and pipe E = 2 in. from main to heel and pipe D corresponding to pipe C will be 1½-in.

Sixth: Note sizes of returns as

H = 1½ in.; J = 1½ in.; K = 2 in.

Seventh: Determine size of supply main after taking off for a group of radiators. Assume N (for this example) to be a 3½-in. pipe. By Table H-1-3, a main of this size will will supply 850 sq. ft. of direct radiation. Subtracting the total of group X, Y and Z (205 sq. ft.) there remains 545 sq. ft. for which pipe L must carry water and this calls for a 3-in. pipe.

Work Problems H-1-14; H-1-15; H-1-16

Some designers believe in using very much smaller sizes for risers and radiator valves than are indicated by Tables H-1-3, H-1-4 or H-1-5. Where a liberal size main is used and a good pitch provided, the author has secured good results in two and three story houses by using risers and radiator valves that correspond to those given in table H-1-6. It is sometimes quite desirable to increase the size of mains slightly and use the smallest possible riser for the sake of appearance especially where pipes are to be run exposed to save expense as in the case of many old house installations. The student should bear this in mind for such conditions.

Work Problem H-1-17

PART H.

HOT WATER HEATING

LESSON 2.

Design Requirements

GRAVITY
WATER HEATING-SYSTEMS.

FACTORS AFFECTING SIZE OF MAINS.

While data by which the size of mains for gravity water heating-systems were given in Tables H-1-3 and H-1-4, included with the preceding lesson, it is not necessarily correct to assume that a main having a given area will supply a stated amount of radiation regardless of the number of units into which the radiation is divided and without regard to the positions of the radiators.

There are two governing factors—volume of water circulated and the velocity of flow. The volume circulated is influenced materially by the cross-sectional area of the pipe, while the internal frictional resistance of the inner surface of the pipe may have a decided effect upon velocity.

When the radiation is divided into many units, the frictional resistance is greater than when the

radiation units are few. The velocity of flow is reduced because of the necessary use of more fittings, and a greater number of bends in and additional length of piping. The rate at which heat is emitted from a radiator is governed by the temperature of the water in the radiator and the velocity at which the water circulates through the radiator.

The sizes of mains when established by the use of tables, such as Tables H-1-3 and H-1-4, should be reduced or increased as rapidly as the changes in radiation will permit and the lengths of all mains to any point should be measured back to the boiler. Risers to any floor in the case of an up-feed system should be proportioned to supply all the radiation above that floor, as well as the radiators installed on the particular floor. In the case of a down-feed system, the riser should be reduced as branches to radiators are taken off.

Work Problem H-2-1

The note at bottom of Table H-1-3, with reference to reduced capacity of mains that are longer than 100 ft., states that the reduction should be in the ratio of $\sqrt{\frac{100}{L}}$. This is applied as follows: Consider a 3-in. main supplying direct radiation—by the table, this size main if not longer than 100 ft. will supply 675 sq. ft. of radiation. If the main is assumed as 150 ft. long, the reduced capacity is found as follows:

First: Divide 100 by the actual length of main.

$$100 \div 150 = 0.6667$$

Second: Take square root of result First.

Square root of $0.6667 = 0.83$

Third: Multiply radiation value from table for the proper size main by result Second and obtain a value for the reduced capacity.

$$675 \times 0.83 = 550 \text{ sq. ft.}$$

Work Problem H-2-2

PIPE SIZING FOR AVERAGE RESIDENTIAL PLANTS

While it should be kept in mind that conditions of installation must always be given consideration when planning a gravity water heating system,

yet, for average residential work a much-used method, and one which is simple to apply, is to determine pipe sizes by the combined area of valves supplied. When this method is used, the area of the main supply as it leaves the boiler should exceed the combined area of all valve connections to all radiators.

It is therefore proper that each student should be able to size a main using valve areas. This method is not essentially different from that presented in the preceding lesson in connection with Tables H-1-1 and H-1-2.

Valve or pipe areas in square inches for sizes from ½-in. to 10-in. diameter are contained in Table H-2-1. In using this table it must be assumed that pipe capacity varies only as the area which, while not entirely correct, permits the use of a simple means of sizing pipe with fair assurance of reasonably accurate results.

TABLE H-2-1
EQUIVALENT VALVE AREAS

VALVE OR CIRCLE DIAM. INCHES	AREA SQ. INS.
½	0.20
¾	0.44
1	0.78
1¼	1.22
1½	1.76
2	3.14
2½	4.90
3	7.06
3½	9.62
4	12.56
4½	15.90
5	19.63
6	28.27
8	50.26
10	78.54

Fig. H-2-1 shows a section of a supply and a return main of an up-feed two-pipe gravity water heating system the piping for which is to be sized

by using valve areas. The radiators on the three floors have areas as follows:

Radiator	A	B	C	D	E	F
Sq. Ft.	48	56	50	40	70	48

Using Table H-1-5, the size of all risers are obtained as follows:

Radiator	A	B	C	D	E	F
Riser Size, in. diam.	3/4	1	1	3/4	1 1/4	1

Using Table H-2-1, the size of the supply main is determined by beginning at the last radiator served as B and working back to the boiler. The last section of the main as U preferably should be made one or two pipe sizes larger than the last riser served in this example—section U will be made a 1½-in. pipe. By Table H-2-1, the area of a 1½-in. pipe is 1.76 sq. in. The area of the riser supplying radiator D is 0.44 sq. in. which, added to the area of U equals 1.76 + 0.44 = 2.20 sq. in., indicating that section V should be 2 in. in diameter. Similarly, the sizes of W, X, Y and Z are found to be: W = 2.20 (V) + 0.78 (F) = 2.98 requiring a 2-in. pipe; X = 2.98 (W) + 0.44 (A) = 3.42 requiring a 2½-in. pipe; Y = 3.42 (X) + 0.78 (C) = 4.20 requiring a 2½-in. pipe; Z = 4.20 (Y) + 1.22 (E) = 5.42 requiring a 3-in. pipe.

The return main is sized by starting at radiator E and determining the areas required to provide increased capacity as other risers enter the return main. The values thus obtained are:

M = two sizes larger than riser to E=3.14 requiring a 2-in. pipe
N = 3.14 (M) + 0.78 (C) = 3.92....requiring a 2½-in. pipe
O = 3.92 (N) + 0.44 (A) = 4.36....requiring a 2½-in. pipe
P = 4.36 (O) + 0.78 (F) = 5.14....requiring a 3 -in. pipe
Q = 5.14 (P) + 0.44 (D) = 5.58....requiring a 3 -in. pipe
R = 5.58 (Q) + 0.78 (B) = 6.36....requiring a 3 -in. pipe

Tabulating all sizes of pipe thus obtained for the runs of Fig. H-2-1, the following table results.

Radiators		Supply Main		Return Main	
Letter	Supply & Return Pipe Size, In. Diam	Section	Pipe Size, In. Diam.	Section	Pipe Size, In. Dia
A	¾	U	1½	M	2
B	1	V	2	N	2½
C	1	W	2	O	2½
D	¾	X	2½	P	3
E	1¼	Y	2½	Q	3
F	1	Z	3	R	3

Work Problem H-2-3

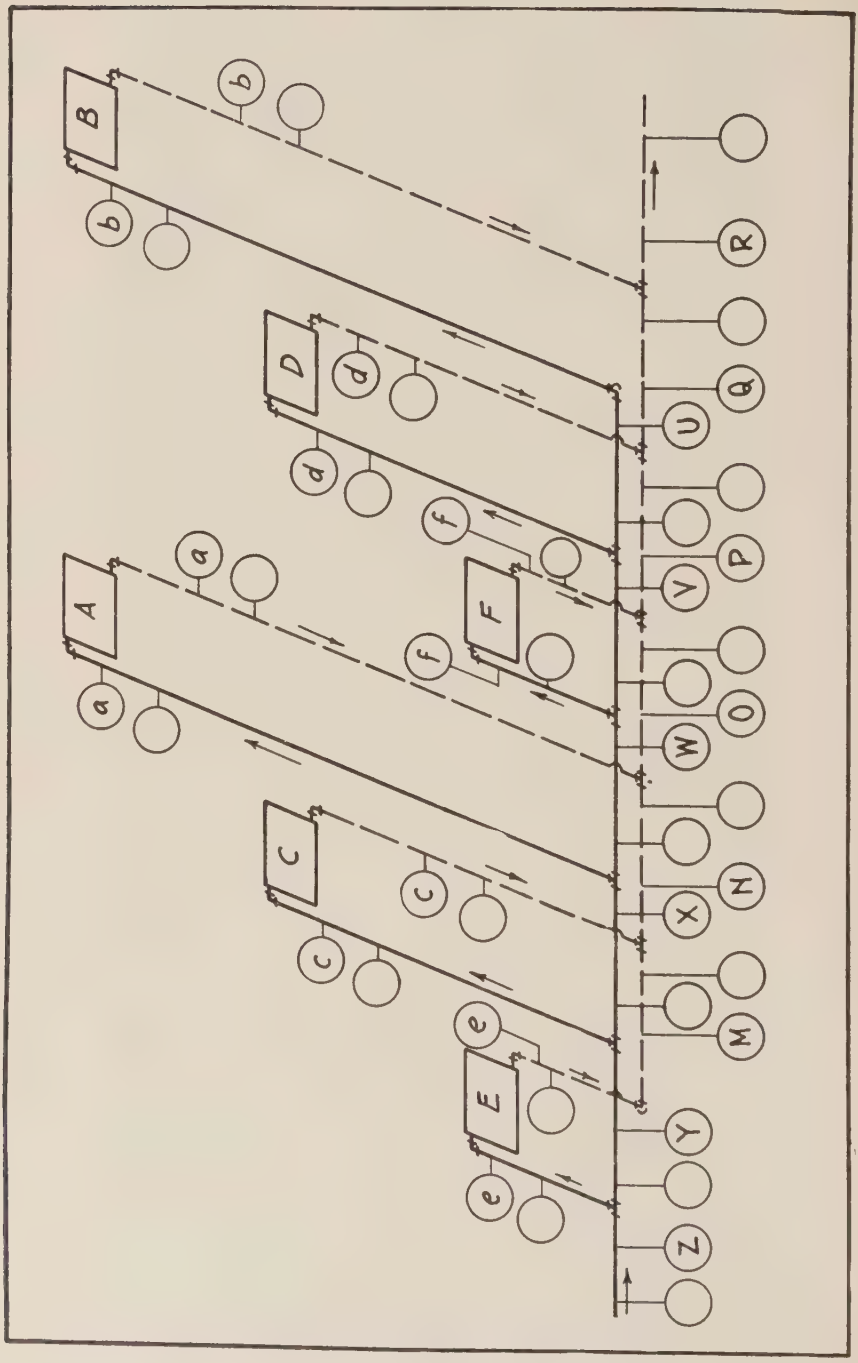


Fig. H-2-1. Reversed Run of Piping for Six Water Radiators.

A starting pipe, as shown in Fig. H-1-9, is often installed between the flow and return main at the boiler in an up-feed system. This pipe may vary in size from 1¼ in. to 2½ in. diameter, depending upon the capacity of the boiler, and is used to assist in the establishment of an initial circulation between flow and return mains before the water in the mains is in full movement.

It is considered good practice for both open and closed-type gravity water heating systems to end the supply main at the connection to a first-floor radiator and to make this connection with a reducing elbow immediately under the vertical upright to the valve, but this may not always be possible. When carried to a first-floor radiator supply riser, the last section of main preferably should be made two pipe sizes larger than the radiator connection, but when the last radiator supplied is on the second floor, one pipe size larger may be ample. However, it is believed advisable generally to carry this last section of a main two pipe sizes larger than the last radiator served and then control the circulation by means of a suitable valve. But no hard or fast rule should be adopted for all cases. Experience and judgment must enter into the consideration of every design.

Generally, branches to radiators should be made equal in size to the upright connection to the radiator valve. If the branch is of exceptional or unusual length, or if it supplies a riser as well as a first-floor radiator, it should be proportioned to carry the additional load or to compensate for the unusual length.

The position or location of the radiator which is to be supplied has much to do with the method of connecting the branch to the main or in the vernacular of the trade "taking off the branch connection."

PIPING DETAILS AND CONNECTIONS

Nothing is more important in designing and installing a gravity water heating system than the method of making branch connections for both supply and return.

Water is a good conveyer of heat. It is also a poor conductor of heat for molecules of water do not quickly give up heat to one another but require a continuous circulation and mixture. Consequently, circulation in a water heating system is of utmost importance for hot water, at the heater, is of no particular use unless the piping is installed so that it will circulate to and from the cooling or radiating surfaces.

Rapidity of circulation means (1) higher average temperature maintained in the radiating surfaces, (2) smaller pipe and radiator sizes due to increased rate of transmission and (3) reduced losses in conveyance because of the smaller pipe sizes. It is equally important that circulation be uniform. These requirements demand a system proportioned throughout as to sizes of mains and branches so that each radiator may receive the proper quantity of circulating water without robbing some other radiator near or far from it.

Proportioning of mains and branches has been touched upon in this and the preceding lesson. It should be realized though and particularly by those who are only beginning the study of gravity water heating systems that a properly-proportioned system might be designed only to fail miserably in operation because branch and other pipe connections were not correctly installed.

The manner of making pipe connections should be very carefully considered by the designer and the design should show by enlarged details or other appropriate manner the relative positions of different fittings used at branch, supply and return points. No other feature of gravity water heating design requires more experienced judgment or contributes more liberally to satisfactory and efficient operation.

The warmest water in a pipe travels along the upper part of the pipe. Therefore if all branch connections to a main were taken off the top, the result would be a short-circuiting of some radiators, with those nearest the boiler receiving the warmest water and the others in varying degree depending upon their distance from the boiler. It is also poor practice to take a branch from another branch. Better control and circulation is assured

by going back to the main for each group of radiators so that the piping system is balanced by each supply serving nearly equal amounts of radiation.

In all systems, the tendency is for the warmest water to seek the highest radiators. This requires that means be employed to control the flow to induce a better circulation in the lower radiators. First-floor radiators should often be favored by separate connections from the mains and, in general, the size of long mains should be reduced only slightly since this will offset the disadvantage of added friction and cooling due to the greater distance from the end of the main to the heater. A liberal and ample size of main assists towards an even distribution of the water throughout the system. Frequent reductions are the cause of sluggishness and short-circuiting.

By introducing additional resistance at the point where the tendency to circulate in one direction may interfere with a necessary circulation in another direction, a good circulation may be assured in the less favored direction. Means of control

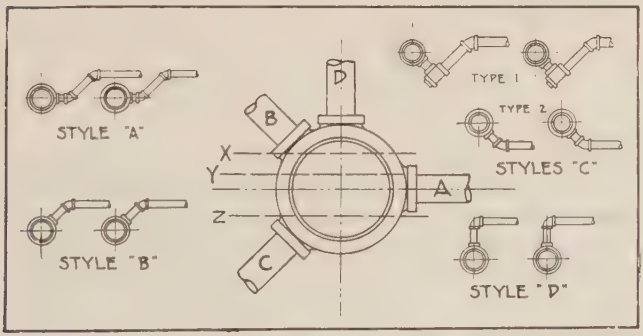


Fig. H-2-2. Styles of Branch Connections to Mains.

may be by special fittings, special pipe connections or by special valves.

BRANCH CONNECTIONS TO MAINS

Four styles of branch connections to mains are shown in Fig. H-2-2, noted as styles "A," "B," "C" and "D." Two types of style "C" connection are shown.

Style "A" connection is used for making a branch connection to the main when the branch is to supply a first-floor radiator or a first-floor radiator and a riser. This connection should generally be used only at points where no reduction occurs in the size of the main.

Work Problem H-2-4

Style "B" connection is used for making a branch connection to the main when the size of the main is reduced where the branch is taken off, otherwise air might collect in the pocket formed at the point of reduction. Air pockets interfere seriously with circulation. Style "B" connection permits any air that might collect at such a point of reduction to pass into the branch pipe, thence into the radiator from which it may be exhausted through the air valve on the radiator.

When the design consists of a principal main with several branch mains, a style "B" connection should generally be used where each branch leaves the principal main.

Work Problems H-2-5, H-2-6

Style "C" connection has a very important position in piping design of gravity water heating systems. In this type of heating system there is always a tendency of the heated water to seek the highest point of the system so that it is quite essential at times to install branch connections for risers that supply radiators on upper floors that reduce this tendency. The use of this style "C" connection under such conditions generally will prevent short-circuiting and any tendency of the flow from an upper-floor radiator blocking off circulation in the main return beyond the point of the connected branch. The more a tee is turned downwards, the more the circulation through the side outlet is retarded. Thus a style "C" connection prevents a branch from "robbing" the circulation to the radiators connected at a greater distance from the boiler.

"Robbing" of circulation is often the condition that spells failure in the operation of many gravity water heating systems by preventing an even distribution of the circulating water and causing what is termed an "unbalancing" of the system.

If the first branches taken off the main get an excessive amount of hot water, there is sure to be a weakening of the circulation in the main as the distance from the boiler is increased. In every installed job, there is a slight difference in the temperature of the water at the top from that at the bottom of the pipe and for this reason, a connection to a first-floor radiator located quite near the boiler often should be made so as to retard the flow through it. Style "C" branch connection frequently offers the proper solution.

Type 1 of style "C" should be used only for radiators which do not require venting as in the case of down-feed systems or for basement radiation where the radiators are located below the main, the air being vented from upper radiators or, if this be down-feed, from the high point of the system.

Work Problems H-2-7, H-2-8.

Style "D" connection has a definite place in gravity water heating piping design but must be used with extreme caution. This connection is applicable for branches that supply radiators that must be favored. If used near the boiler especially for an upper-floor radiator, it will almost always cause undesirable circulation with the result that the particular radiator thus served will be excessively hot while others are relatively cold. The designer should be very careful in specifying this style connection.

Too much importance cannot be attached to the necessity of using a proper style of branch connection. The turning of a tee up or down often may spell success or failure.

The sketch accompanying styles of branch connections in Fig. H-2-2 illustrates the effect of placing the outlet of the tee in several different positions. If the top connection (style "D") or

the 45° connection (style "B") is used, either will appropriate the circulation down to the dotted line marked X. With the tee outlet turned directly horizontal (style "A"), the branch will appropriate the circulation only up as high as indicated by the dotted line Y. In the case of a tee turned downwards 45° (style "C") the level of branch flow from the main is reduced to that of the dotted line Z.

REDUCTION IN SIZE OF MAIN

When a main or branch is reduced in diameter, an eccentric fitting should be used so as to avoid an air pocket and keep the bottom of the inside surface of the main or branch in line. Eccentric tees and eccentric reducers serve this purpose as indicated in Fig. H-2-3 where the right and wrong methods are illustrated. The use of eccentric tees prevents lodging places for water and assures a more even flow along the main than where double-reducing fittings are used such as a straight reducing tee and an eccentric bushing connected with a close nipple. If a reduction in a main is required and an eccentric tee is not available, it is better to use full size on the run and an eccentric reducer as this assures full capacity and an even flow line to the reducer.

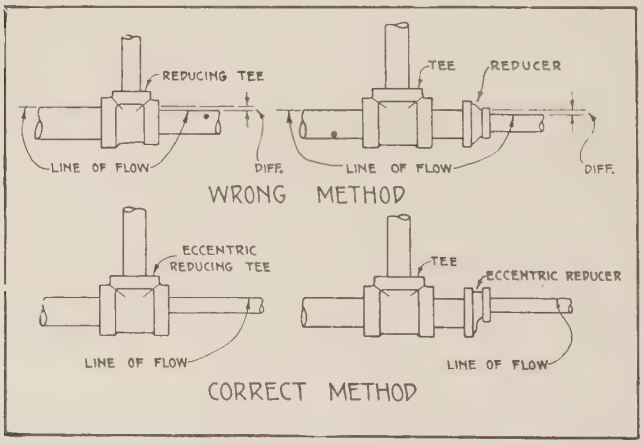


Fig. H-2-3. Reduction in Size of Main—Use of Eccentric Fittings.

When ordering or inquiring concerning eccentric tees, it is advisable to submit a sketch showing the exact position in which the fitting is to be placed and the eccentric openings. In specifying the size of a tee, give the diameter of outlet openings by stating the run-openings first followed by the side outlet diameter.

Work Problem H-2-9

RADIATOR CONNECTIONS AND RISERS

Various details should be observed in making connections to radiators and the manner in which run-outs from the same riser to two radiators of equal area on the same or on different floors is always deserving of serious consideration. A number of connection and fitting details are shown in Fig. H-2-4 and will be explained by the assigned detail number and referred to in subsequent lessons.

Detail 1 (Fig. H-2-4) shows a method of connecting radiators when piped as for a one-pipe gravity water heating system. The radiator connections are usually made top and bottom, with a straightway quick-opening or gate water radiator valve with union placed as shown.

The quick-opening type of valve can be fully opened or closed by one-quarter turn of the handle. It must be connected so that the current of water will move in the direction indicated by the arrow on its side. This valve may be obtained in stock sizes of $\frac{3}{4}$-in. to 2-in. diameter. Water radiator valves of this type are provided with a hole in the disc which allows for slight circulation when the valve is closed. If a steam type of radiator valve is used for gravity hot water service, it should have a small hole through the bridge wall.

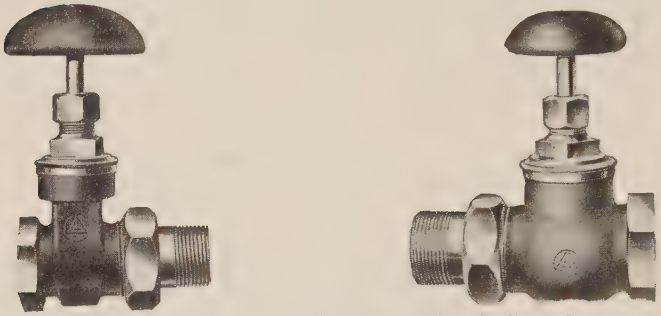
The gate type is equipped with non-rising stem. This valve is carried in stock sizes of $\frac{1}{2}$-in. to 2-in. diameter.

Work Problem H-2-10

Detail 2 (Fig. H-2-4) shows the same connections as detail 1 with a control valve placed on the return connection to radiator. This valve on the

STRAIGHTWAY RADIATOR VALVES.

Gate Type. **Globe Type.**



Courtesy American Radiator Company.

return line should be a valve fitted with lock and shield. If the vertical pipe is made the same size above, below and between points A and B, there is danger of the flow being shunted past the radiator so that the radiator is liable to get too little, rather than too much, water. The proportioning of pipes for such a run as shown will be covered in a succeeding lesson.

Work Problem H-2-11

Detail 3 (Fig. H-2-4) shows a water radiator with double-riser connections. A straightway (or angle) quick-opening water radiator valve with union is installed on the supply side and a key-operated valve on the return side. While the use of two such valves necessarily increases the cost of the installation yet there is perhaps little doubt that of all methods of controlling circulation in a gravity water heating job, the most satisfactory and reliable method is by the use of special control valves. Furthermore, when the extra cost of special fittings and the extra time involved in making special connections are taken into consideration, it is not unlikely that to install a control valve is very nearly as cheap as any other method of control.

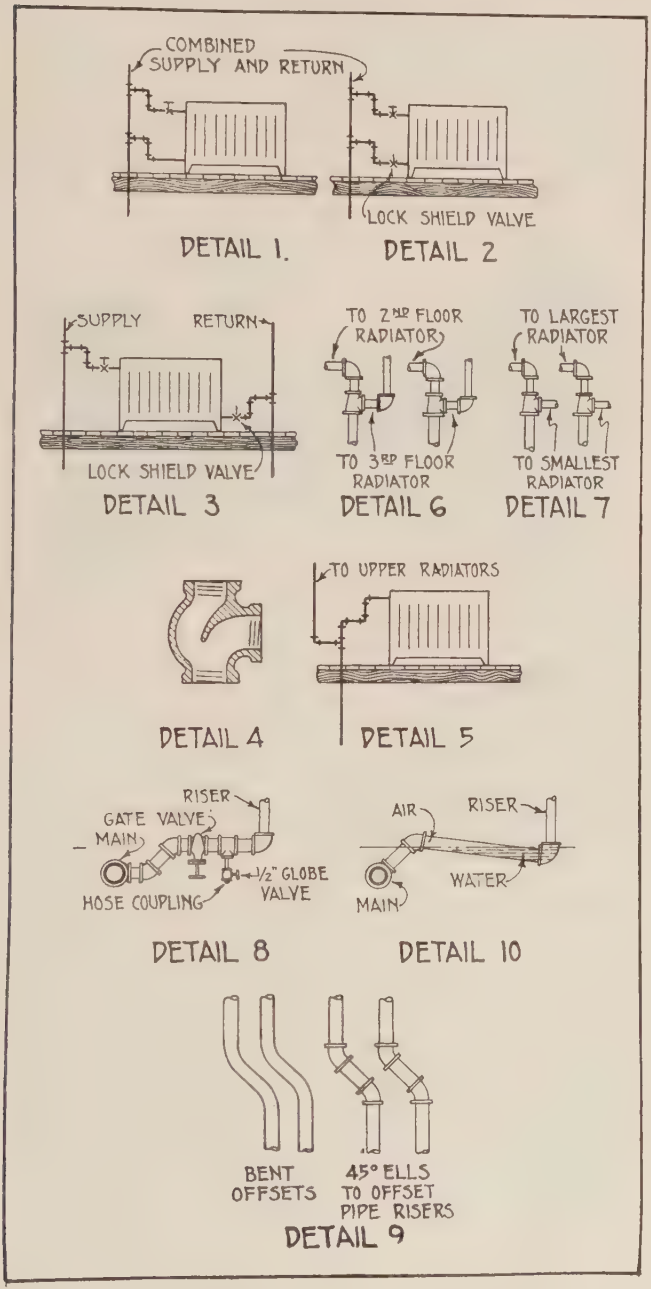
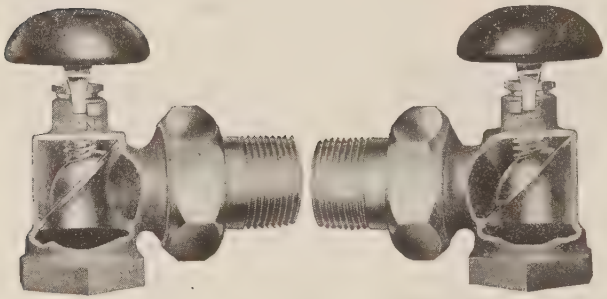


Fig. H-2-4. Piping Details and Connections

QUICK-OPENING WATER RADIATOR VALVE.

Valve Open. **Valve Closed.**



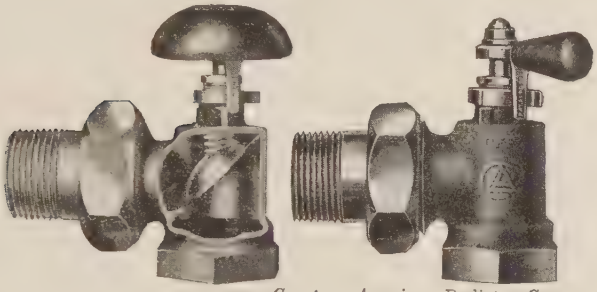
Courtesy American Radiator Company.

The results secured with control valves are generally considered superior. The valves may be set at any desired opening or left entirely open if the circulation is satisfactory. With a radiator controlled as indicated in Detail 3 and with all piping installed with proper pitch so that air pockets are eliminated, a positive control of circulation is almost assured. By commencing at the hottest radiators and gradually closing the return valve until the resistance to flow through it is just sufficient to induce the proper circulation in all the other radiators, the system can be regulated so as to operate at uniform temperature. After the entire system has once been adjusted, the return valves can be set permanently and the radiators controlled by means of the supply valves.

Work Problem H-2-12

EQUALIZING HOT WATER VALVES.

These valves are used to insure uniform flow through all radiators without the use of washers or retarders in connections. Obtainable in stock sizes ½-in. to 1½ in.



Courtesy American Radiator Company.

Detail 4 (Fig. H-2-4) shows a special fitting called an O. S. distributor. This fitting assists towards insuring positive, uniform circulation of hot water. The deflector lip prevents the establishment of a full flow of the hot water to the upper floors and assures a more even distribution to all radiators on the line. The use of this fitting may often result in a considerable saving in time, labor and fittings. It is obtainable in a great variety of sizes ranging from ½ to 2½ in.

Work Problem H-2-13

Detail 5 (Fig. H-2-4) shows pipe connections that produce practically the same result as the special O. S. fitting. The hot water rises straight to the top of the pipe where there is only one path open for it, namely, into the radiator. The supply for other radiators on floors above is taken from the side of the riser somewhat below the connection to the lowest radiator. Connections of this kind are repeated at each of the lower radiator connections but need not be used on the upper levels as these radiators do not require favoring.

Detail 6 (Fig. H-2-4) shows the kinds of fittings to be used for piping like Detail 5. The importance of making connections in this manner is generally realized since hot water rises more readily to upper floors and always seeks the path of least resistance. Thus, the second-floor radiator is favored by being connected from the top of the tee and the more active flow to the third floor radiator is restricted by the fact that the riser is connected into the side.

Work Problem H-2-14

Detail 7 (Fig. H-2-4) shows a method of supplying two radiators of unequal size located on the same level and connected to the same riser. The larger radiator should be supplied from the top of the tee and the smaller from the side thereof. These connections will favor the radiator to which the circulation will be more active, since a greater volume of water is required for the larger radiator if both radiators are to heat evenly.

If two radiators of the same size and located on the same level are supplied by the same riser, the circulation may be equalized by reducing the size of the top connection.

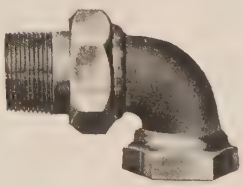
Work Problem H-2-15

Detail 8 (Fig. H-2-4) shows how run-outs to radiators or branch arms may be equipped with a gate valve for entirely closing off the supply in case this may be desirable and with a globe valve and hose connection, in order that the water may be drawn off from the piping when repairs are needed or to guard against freezing when not in use. The gate valve should be installed with the handle looking down and the globe valve as shown.

Work Problem H-2-16

Valves and elbows and other fittings introduce additional frictional resistance within the flow lines. In gravity water heating systems where the motive head is small, this may be a serious factor, especially in the smaller pipe runs in which frictional resistance is comparatively much higher than for the larger sizes of pipes. In some cases

UNION ELBOW FOR WATER RADIATORS.



Courtesy American Radiator Company.

it may be found advantageous to limit the use of elbows by bending the smaller sizes of pipes where offsets are required as indicated by detail 9 (Fig. H-2-4).

Detail 10 (Fig. H-2-4) illustrates the necessity of pitching the branch properly. As illustrated, the air is pocketed, circulation is practically stopped and no means exist by which the air may be removed. Such condition should be avoided.

APPLICATION OF PIPING DETAILS

In Fig. H-2-5, three details are shown, each of which consists of radiators that are to be piped. Detail 1 (Fig. H-2-5) shows two radiators of unequal size located on the same level; Detail 2 (Fig. H-2-5) shows two radiators of equal size located on the same level; and Detail 3 (Fig. H-2-5) shows a main leaving a boiler, the main is to supply seven radiators aggregating 410 sq. ft. of direct radiation, with three radiators on the first floor and four on the second.

Work Problems H-2-17, H-2-18, H-2-19

In Fig. H-2-6 there is shown a piping run for a two-pipe up-feed water heating system. It is desired that this layout be supplied as an installation print having all sizes marked thereon; also that the style of every connection from the main be specified.

Work Problem H-2-20

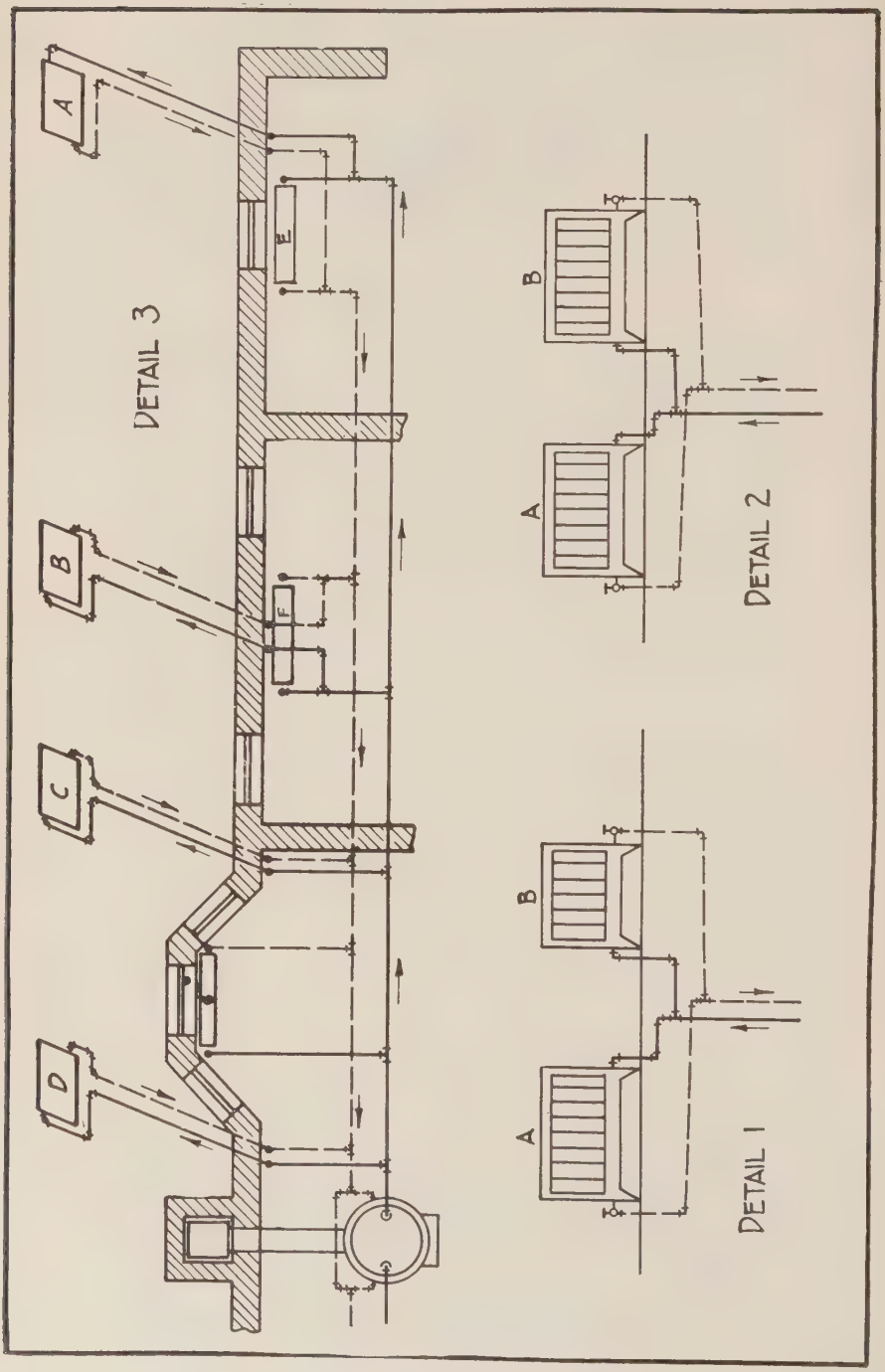


Fig. H-2-5. Application of Piping Details and Connections.

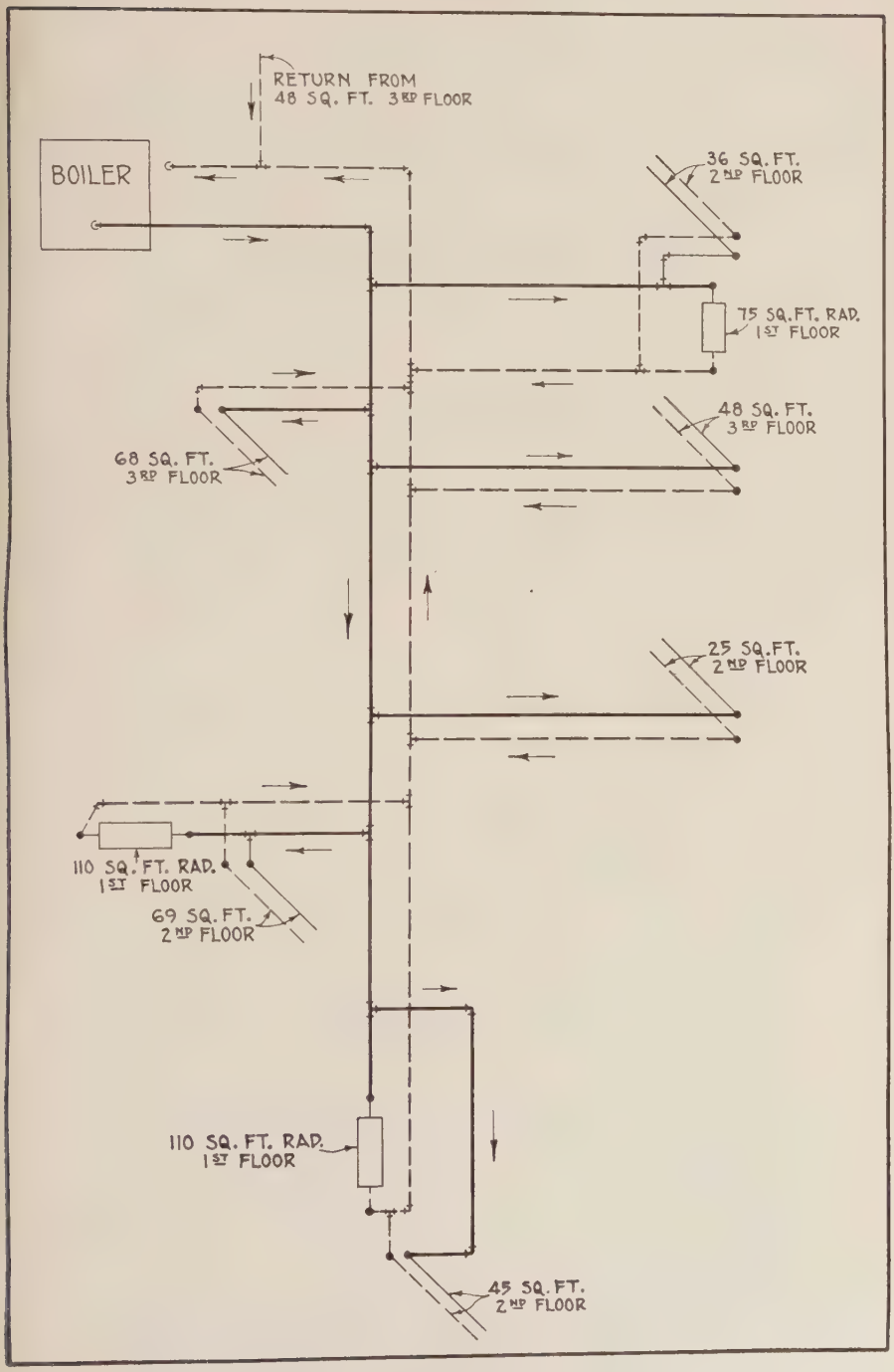


Fig. H-2-6. Arrangement of Piping for a Two-Pipe Up-Feed Water Heating System.

PART H.

HOT WATER HEATING

LESSON 3.

Up-Feed and Down-Feed Systems

GRAVITY

WATER HEATING SYSTEM

UP-FEED ONE-PIPE SYSTEM

This type of water heating system is quite generally used, especially for buildings larger than residences where an up-feed hot water system is to be installed.

Fig. H-3-1 shows a typical layout with three banks of radiators. The supply main should be started close to the basement ceiling just above the boiler, as at point X, and should grade in the direction of flow downward uniformly ¾ in. in 10 ft.

The supply main should not be reduced in size as branches are taken off but should be carried full size for the entire circuit with pipe of ample

capacity to serve the total radiation. Shortly after the last branch is served, the main should drop vertically, as at point Y to a point, as at W, such that the pitch from W to Z will be the same as from X to Y (Fig. H-3-1).

Supply branches, as at M, N and O, should be taken from the top of the main or at an angle of 45°, as shown by connection details at the right of Fig. H-3-1. The 45°, branch connection should usually be used for branches near the boiler or for those that supply only upper-floor radiators.

Return branches, as at P, Q and R, should be connected into the side or bottom of the return main, as shown by connection details at right of Fig. H-3-1; the side inlet being used for the less-favored radiator groups, while the 45° downward connections afford a means for slightly checking the flow through certain groups of radiators so as to assure a more uniform circulation throughout the entire system.

Where a branch supplies radiators located on several floors, the upper-floor radiators may be made to augment the circulation to the first-floor radiators by taking the branch for the upper-floor radiators from the side of the branch running to the first-floor radiator, as shown at A, Fig. H-3-2. The first-floor branch should be run full size from B to C in order to favor the lower radiator.

Connections to and from the radiators should be made as shown in Fig. H-3-2. The supply connection is made at the top of the radiator, using a union elbow, and the return at the bottom, using a quick-opening water radiator valve with union connection. Thus only one valve is required to control the radiator.

Since in a one-pipe main, the temperature of the supply water is gradually lowered, as it passes along the main, due principally to the dumping into it of the return water from the radiators along its course, it is advisable to increase the area of the last group of radiators served by 5% to 10% and to increase the size of branch and riser connection at the end of the main by one pipe size.

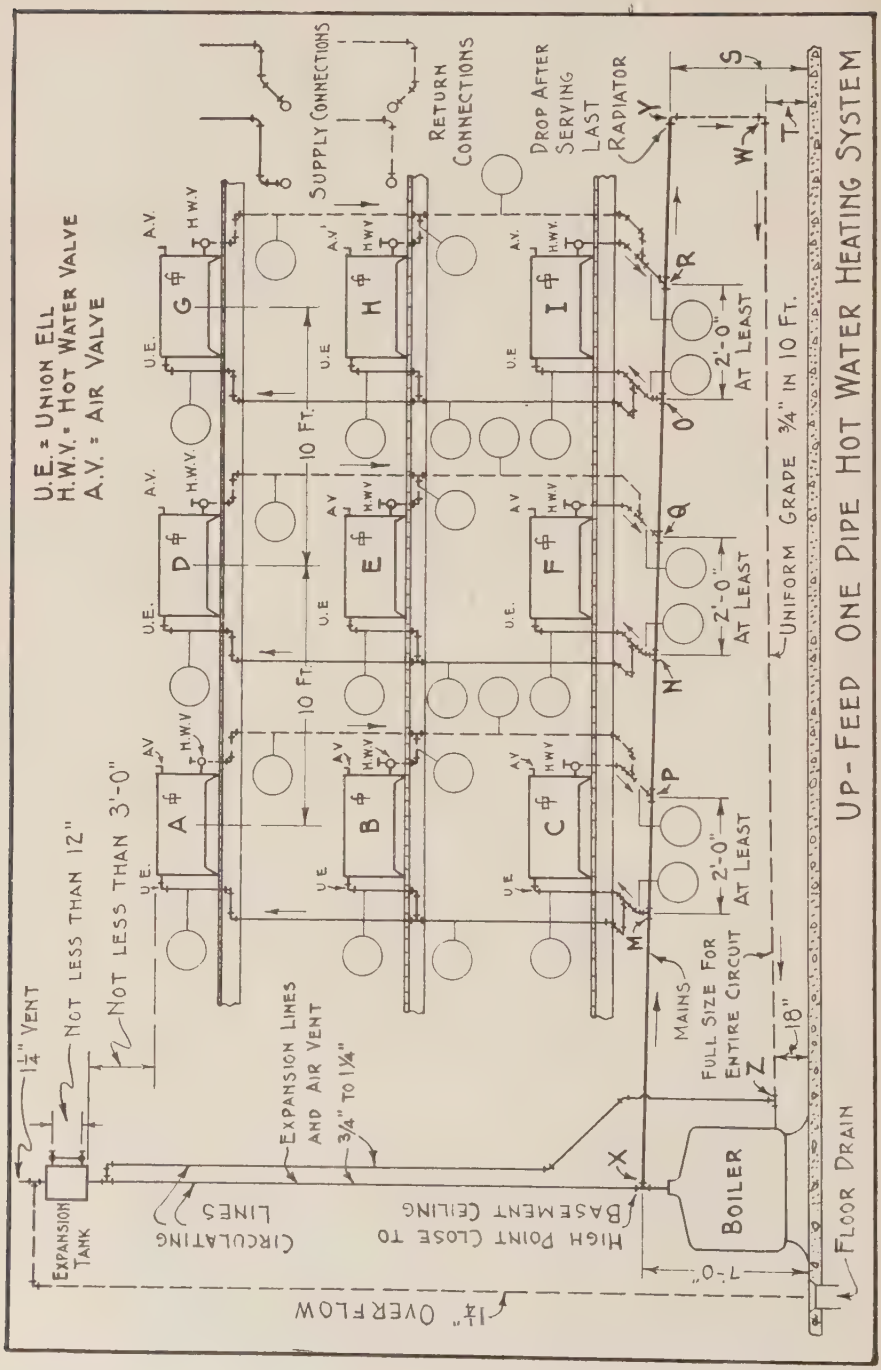


Fig. H-3-1. Typical Up-Feed One-Pipe Water Heating System.

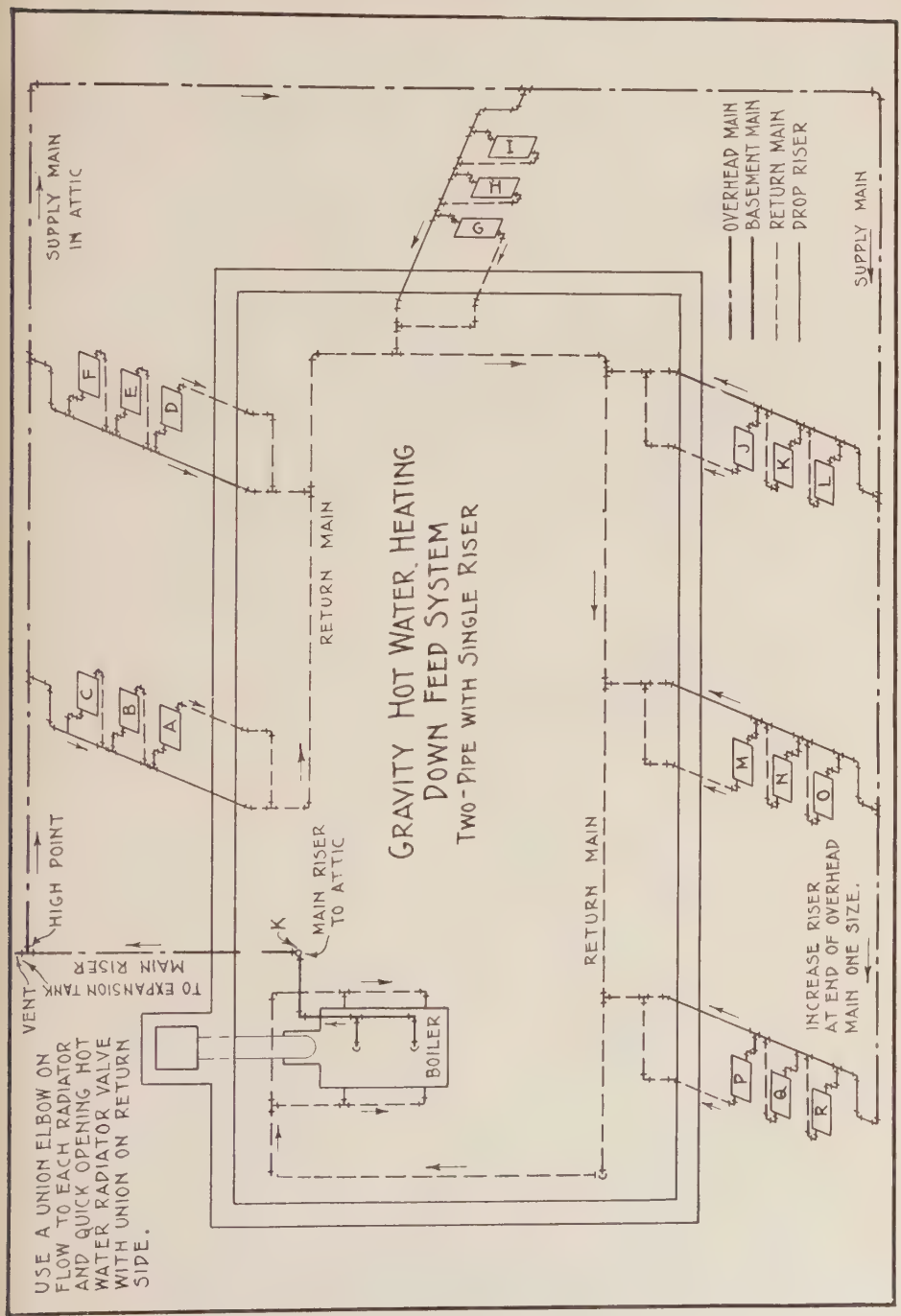


Fig. H-3-3. Typical Basement Plan for a Down-Feed Two-Pipe Water Heating System with Single Riser.

Pipes may be sized and proportioned from Tables H-1-3 and H-1-1 or Table H-1-2.

Work Problems H-3-1, H-3-2, H-3-3

DOWN-FEED WATER HEATING SYSTEM. TWO-PIPE WITH SINGLE RISER

A typical layout for this system is shown in Fig. H-3-3. The supply main is carried to the attic as soon as possible after leaving the boiler through a main riser, as shown at K.

The main riser must be firmly supported in a suitable manner (See Fig. H-3-4). At the high point in the attic, the main should be provided with an enlarged cooling chamber to permit rapid separation of air that collects at the top and removal of it to the expansion tank. This enlarged

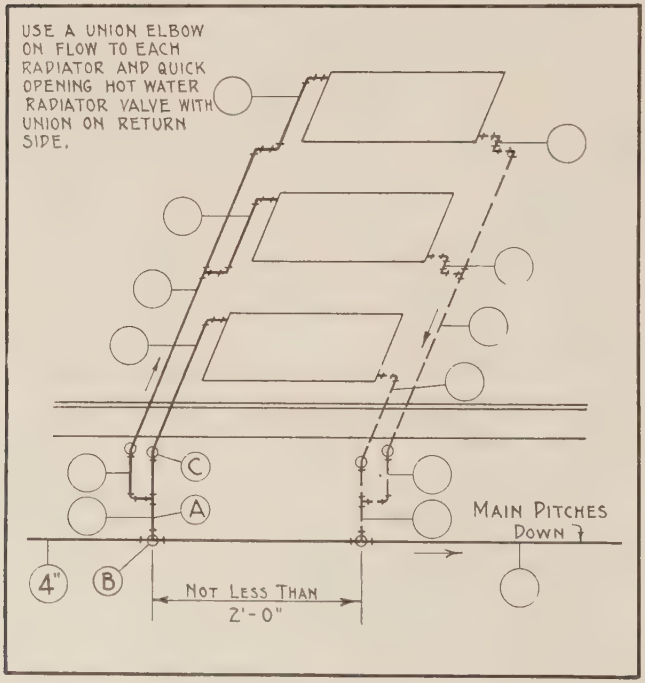

USE A UNION ELBOW ON FLOW TO EACH RADIATOR AND QUICK OPENING HOT WATER RADIATOR VALVE WITH UNION ON RETURN SIDE.
C
A
MAIN PITCHES DOWN
4"
B
NOT LESS THAN 2'-0"

Fig. H-3-2. Typical Radiator Group for Up-Feed One-Pipe System.

cooling chamber at the head of the riser is made of a bushed tee having the run twice the diameter of the riser, with the outlet the same size as the attic main.

The attic main is then carried around the building above the radiators, to be fed in a manner similar to that in which the supply main of an up-feed system is carried around the cellar below the radiators.

The main riser can usually be made considerably smaller than the horizontal main in the basement and attic to which it connects since the vertical position of the pipe permits more rapid movement of the water through it. The size of the main riser should be taken from Table H-3-1. The sizes for the horizontal attic run may be taken from Table H-3-2.

A comparison of Tables H-3-1 and H-3-2 will show how much smaller the riser may be, as compared to the horizontal run to which it connects. For instance, if the radiation to be supplied is 900 sq. ft., by Table H-3-2, the horizontal supply pipe should be 3 in. in diameter whereas by Table H-3-1, the vertical riser need be only 2½-in. pipe.

Work Problem H-3-4

The flow main in the basement from the boiler to the foot of the main vertical riser should grade up from the boiler while in the attic, the flow main should grade down from the enlarged chamber to the end of the run. In each case, the slope should be ¾ in. in 10 ft. or better.

Radiators are supplied through drop risers taken from the side or bottom of the attic main. The use of two elbows affords means for properly grading the branches and providing for expansion therein. The method of connecting a group of radiators is shown in enlarged view in Fig. H-3-5, and sizes for drop risers are to be taken from Table H-3-3, using the column marked "single riser."

Special care should be taken to proportion each section of the riser for the amount of radiating surface that it must serve as both a supply and a

GRAVITY WATER HEATING - SYSTEM
DOWN FEED OPEN TYPE WITH ATTIC MAIN
PIPE SIZES IN TERMS OF RADIATION

TABLE H-3-1

MAIN RISER	
PIPE SIZE	RADIATION SQ FT
1¼	200
1½	350
2	600
2½	1200
3	2000
3½	2500
4	3500
4½	4500
5	6000
6	10000
7	12000
8	15000
NOTE:- SEE FIG. H-3-4.	

TABLE H-3-2

MAINS 100' LONG	
PIPE SIZE	RADIATION SQ FT.
1¼	150
1½	250
2	350
2½	540
3	900
3½	1300
4	1800
4½	2400
5	3200
6	5000
7	7200
8	10000
10	13000
12	16000

TABLE H-3-3

DROP RISERS		
PIPE SIZE	RADIATION-SQ.FT.	
	SINGLE RISER	DOUBLE RISER
¾	25	50
1	80	120
1¼	120	200
1½	200	350
2	400	600
2½	750	1200
3	1000	2000
NOTE:- RADIATOR TAPPINGS SAME AS PIPE SIZE AND FOR SAME SIZE RADIATOR PIPE SIZE IS THE SAME FOR ANY FLOOR. INCREASE RISER ONE SIZE AT END OF OVERHEAD MAIN.		

MAIN AND DROP RISER TABLES BY C. B. THOMPSON. HARDING & WILLARD

return line. Branches from the drop riser to the radiator are also sized by Table H-3-3 and a return from a radiator is made the same size as the supply to it. For radiators having equal areas, but located on different floors, the pipe size is the same.

A study of Fig. H-3-5 shows that, in this down-feed system, water is always circulating through the flow riser, regardless of whether or not any or all the radiators are closed off.

The piping for a group of radiators is proportioned as given below for the group A, B, C, shown in Fig. H-3-5, if they have the following areas.

Radiator.....	A	B	C
Area, sq. ft.....	40	70	60

Total radiation to be supplied=40+70+60=170 sq. ft.

By Table H-3-3, for 170 sq. ft., a 1½-in. pipe is required so (a)=1½ in.

The pipe size to each radiator becomes as follows:

For radiator C....60 sq. ft. (b)=1 in.
For radiator B....70 sq. ft., (c)=1 in.
For radiator A....40 sq. ft., (d)=1 in.

The returns being the same size as supply become:

For radiator C..... (e)=1 in.
For radiator B..... (f)=1 in.
For radiator A..... (g)=1 in.

Section (h) carries water to serve only radiators B and A or 110 sq. ft. A 1¼-in. pipe is required. Section (i) carries the supply for radiators B and A, and also the return water from radiator C. Its capacity must therefore be 170 sq. ft. of radiation, thus requiring a 1½-in. pipe. Section (j) must have a capacity equal to radiators A and C, or 100 sq. ft. which requires a 1¼-in. pipe. Section (k) is similar to section (i) and requires a 1½-in pipe. Section (l) must have a capacity equal to radiators B and C, or 130 sq. ft. which requires a 1½-in. pipe. Section (m) will be made the same size as (g) and section (n) should be the same as (a).

Tabulating the pipe sizes thus determined for the group of radiators in Fig. H-3-5, the following obtains:

Pipe Section	Size, In. Diam.	Pipe Section	Size In. Diam.
(a)	1½	(h)	1¼
(b)	1	(i)	1½
(c)	1	(j)	1¼
(d)	1	(k)	1½
(e)	1	(l)	1½
(f)	1	(m)	1
(g)	1	(n)	1½

Work Problem H-3-5

If a down-feed system is properly installed, no air valves are required, but special attention should be given the manner in which the radiator branches are connected to the riser so as to assure the escape of any air up the riser and into the overhead main from where it will be vented through the expansion tank. Each radiator should be connected on the flow side with a union elbow, and a quick-opening water radiator valve with union should be used on the radiator return side.

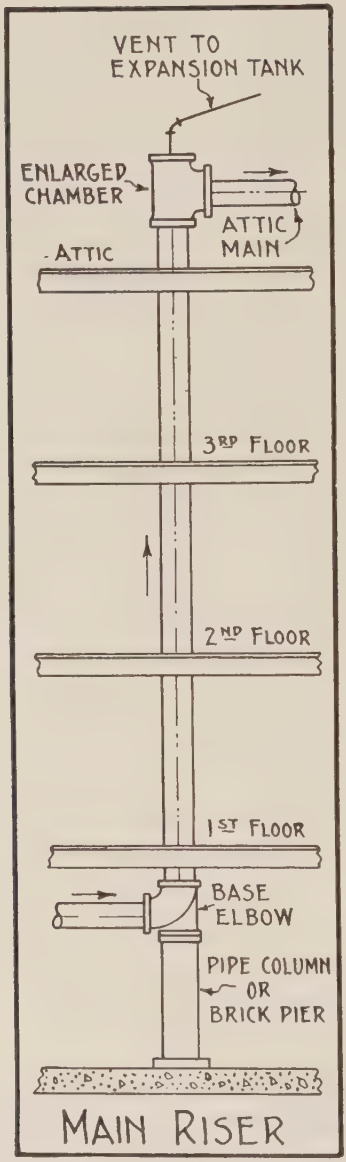


Fig. H-3-4. Main Riser Detail for Typical Down-Feed Water Heating System.

The size of the supply main in the attic should be reduced as branches are taken off, while the return main in the basement should be increased as the branch returns from the different radiator groups

enter it. Pipe sizes should be equalized or proportioned as explained in a previous lesson.

The return main (See Fig. H-3-3) begins under the first radiator served by the overhead main and is run "reversed" so that the water in it flows in the same direction as that in the overhead main. Thus the length of water travel to all radiators is

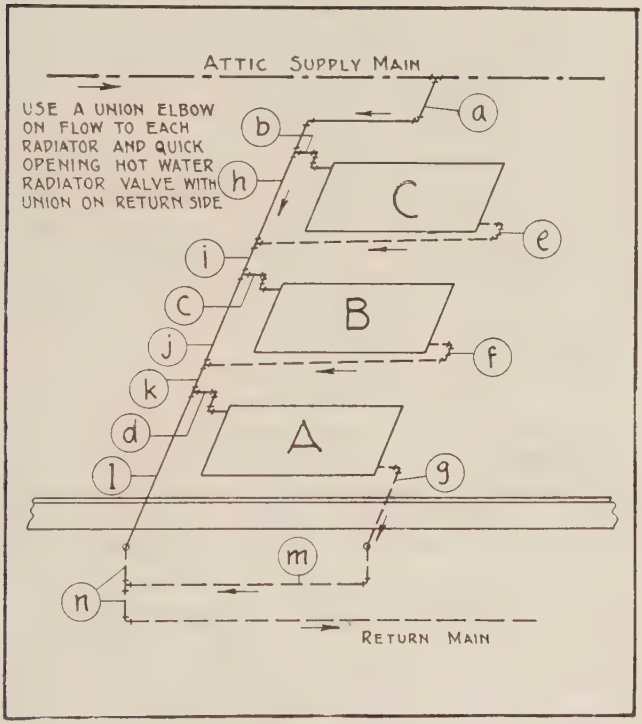


Fig. H-3-5. Typical Radiator Group for Down-Feed Single-Riser Water Heating System.

equalized and consequently equal resistance to flow is obtained as explained in a previous lesson.

Work Problem H-3-6

In what has preceded relating to the design and installation of water heating systems, the student has been instructed to use certain tables for determining and specifying sizes for horizontal mains, risers, branches and radiator connections. It is important that the student be duly impressed

with the fact that no hard and fast rules that apply to every case can be laid down. In order to design and install a hot water gravity circulating system in which the circulation will assure practically even warming-up of the radiators, all conditions of the particular installation must be considered.

For the sake of uniformity and on account of the impossibility of giving all the details that would exist for different jobs, the student should always endeavor to follow instructions that accompany the statements of the assigned problems as to tables or methods that should be used, as well as the many special instructions given.

Every hot water design should be tackled in a systematic manner. When a student has completed this course and is preparing original designs in practice, he may adopt a system that better suits his needs. However, it is believed that the best results will be obtained by observing, in general, the following.

First: Consider the size of the radiator, its location and the cooling effect upon the water within it, in deciding upon the size of connections. A consideration of its location is necessary in order to determine the relation of friction to flow of water to it, compared to the flow to other radiators.

Second: After all branch connections have been sized, proceed to size all branches that supply more than one radiator by making the pipe or pipes equal to or greater in area than the area of the radiator connections from the pipe supplying them.

Third: After all such pipes (under SECOND) have been sized, proceed to size the different parts of the main so that its area at any point is equal to or greater than the area of all pipes supplied past that point.

If a design is based entirely and only on radiating surface, there is likelihood of having a short circuit in the system by having one or more groups of radiators near the boiler containing slightly less radiation than that required for a size larger pipe and the radiators near the end containing a small amount of radiation for their pipe size. The main designed on the basis of radiating surface would be large near the boiler and small near the far end. It is possible that the area of the main toward the

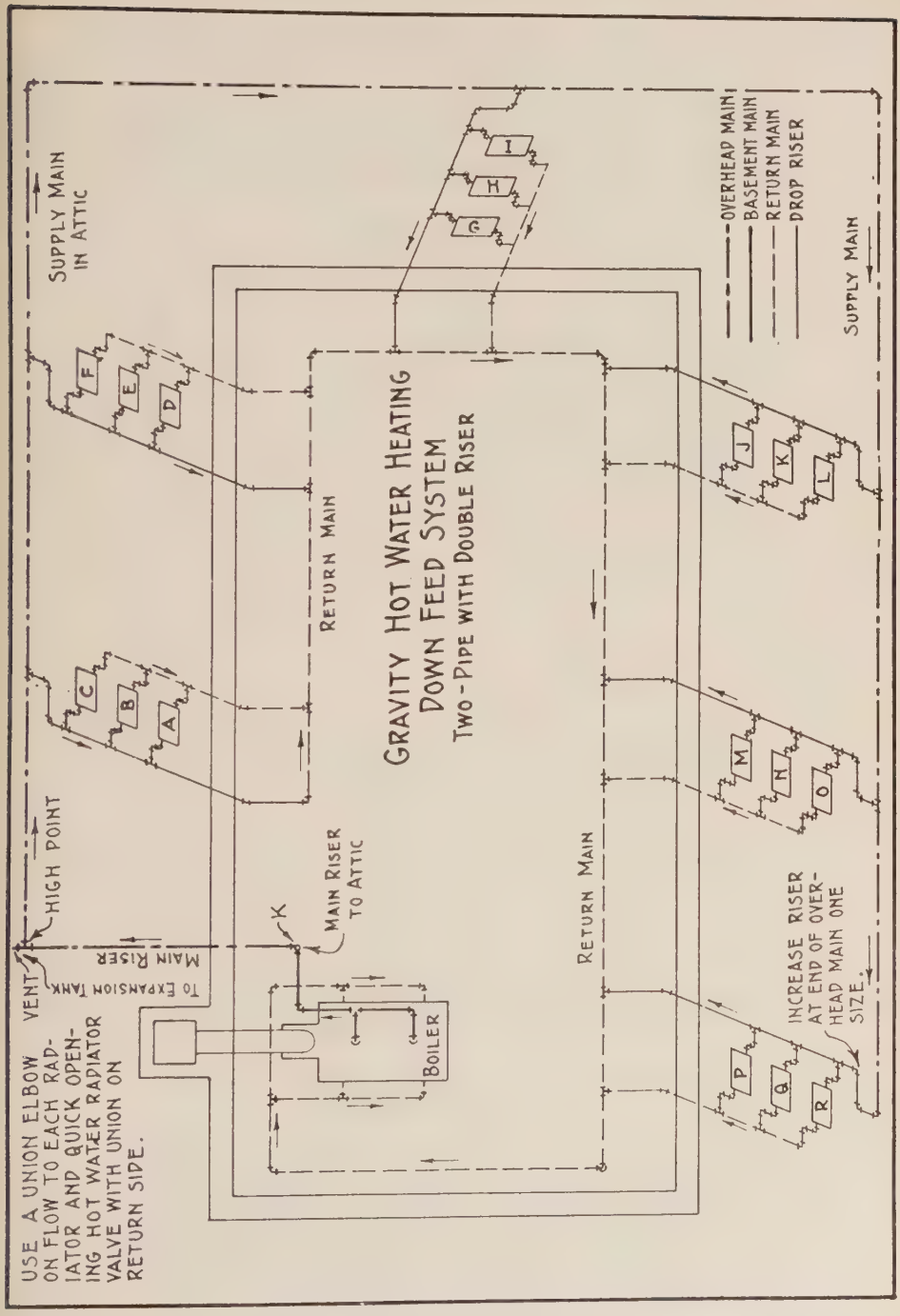


Fig. H-3-6. Typical Basement Plan for a Down-Feed Two-Pipe Water Heating System with Double Riser.

far end would be much smaller than the area of the branches. This condition would most likely cause a short circuit of the water through the radiators near the boiler and either fail to reach the far end radiators or be so slow in reaching them that the radiators could give no useful service.

Work Problem H-3-7

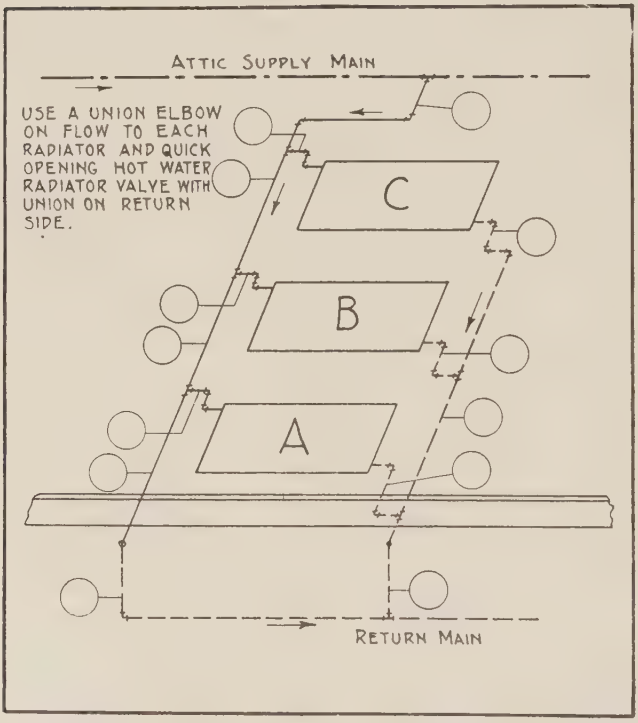

ATTIC SUPPLY MAIN
USE A UNION ELBOW ON FLOW TO EACH RADIATOR AND QUICK OPENING HOT WATER RADIATOR VALVE WITH UNION ON RETURN SIDE.
C
B
A
RETURN MAIN

Fig. H-3-7. Typical Radiator Group for Down-Feed Two-Pipe Double-Riser Water Heating System.

DOWN-FEED WATER HEATING SYSTEM. TWO-PIPE WITH DOUBLE RISER

A typical down-feed, two-pipe, with double riser, water heating system is shown in Fig. H-3-6. This system is much like the system with single riser as shown in Fig. H-3-3. It will be noted that there are two drop risers, one for the supply and one for the return.

A group of radiators piped for this system is shown in Fig. H-3-7. Double-riser piping permits of somewhat smaller pipe size. This is apparent from a study of the second and third columns of Table H-3-3. For instance, a ¾-in. pipe will supply 50 sq. ft. of direct radiation when used as a double riser whereas this amount of radiation with a single riser should have a 1-in. pipe. The last column of Table H-3-3 should therefore be used for proportioning pipes for the down-feed two-pipe, with double-riser system.

The main riser is installed as shown in Fig. H-3-4, the horizontal main is carried around the basement in a similar manner to that shown in Fig. H-3-3 and the return should be run "reversed."

The determination of pipe sizes for a radiator group is done similarly as explained above for the group shown in Fig. H-3-5.

Work Problems H-3-8, H-3-9, H-3-10

PART H.

HOT WATER HEATING

LESSON 4.

Application of Down-Feed Systems

GRAVITY

WATER HEATING-SYSTEMS

APPLICATION OF DOWN FEED SYSTEM

In the preceding lesson, the principle of the down-feed water heating system was presented and discussed. It is important that full consideration be given this system of heating since it offers a solution for many problems where an owner may insist on a water heating plant because of its flexibility.

There is a feeling among many in the heating trade that the application of gravity water heating should be limited to buildings of only moderate size, preferably square in shape or but slightly oblong. To attempt to heat a building that does not fall in this rather restricted class with a gravity water heating system is considered by many to be a harbinger of trouble and argues in favor of steam or a forced hot water job.

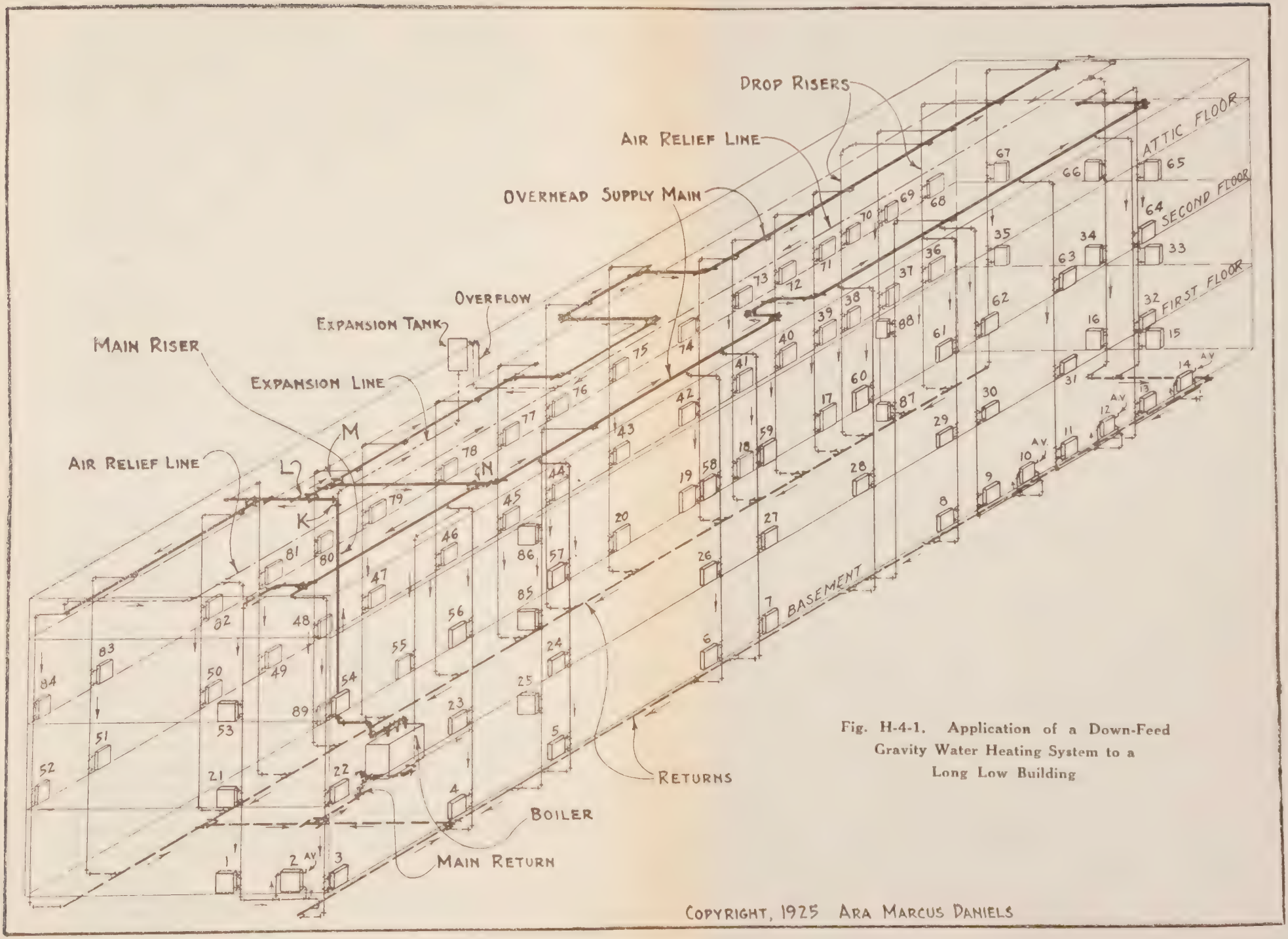


Fig. H-4-1. Application of a Down-Feed Gravity Water Heating System to a Long Low Building

In a locality where the outside temperature may be chilly for long periods during the Spring and Fall, the so-called "flexibility" of a water heating system has much to commend it. It is often possible in the case of a properly-designed and installed gravity water heating system to maintain the desired inside temperature of say, 68° or 70° F. by carrying the water in the radiators at no more than 100° to 120° F. On the other hand for low winter temperatures, the temperature of the water may be carried at 180° to 200° F., although it is in the interest of economy and good design to figure on the temperature of the supply to radiators at 180° F. and the return therefrom at 160° F.

The application of a down-feed gravity water heating system to a long low building having two floors above the basement and consisting of many private rooms on two sides of a long lengthwise corridor is shown in Figure H-4-1.* This layout has been adapted from an actual installation in a building about 175 ft. long by about 40 ft. wide, situated at a relatively high elevation where temperatures as low as 35° to 40° F. below zero may occur several times during a winter with 20° F. below zero taken as the basis of design.

As shown in Figures H-3-3 and H-3-4 (of the previous lesson) a main riser is carried from the boiler to the high point (marked K) of the circulating system. An expansion line is run from point K to the bottom of an expansion tank located at an elevation higher by a few feet.

The overhead mains are then run in an attic space and are graded downwards towards the last radiator served. At point L, one branch is taken off one end of the T and at point M the main divides into two equal-size branches. The branch on the near side of the building again branches at point N. Drop risers are taken from the main at different points to supply the radiators shown. The radiators and drop risers on the near side of the building are drawn with slightly heavier lines than those on the far side so that the connections to the drop risers may be more easily distinguished.

* Described by Mr. T. F. Moffett in The Plumbers Trade Journal, Steam and Hot Water Fitters Review, Feb. 1, 1925.

All drop risers near the center of the supply runs are taken from the mains as shown in Detail 1 of Fig. H-4-2. Each drop riser is made the same size throughout its entire length. After supplying the radiators, the bottom of the riser is led into the return line. The returns are carried in trenches below the basement floor and finally brought together into a main return which enters a return header at the boiler.

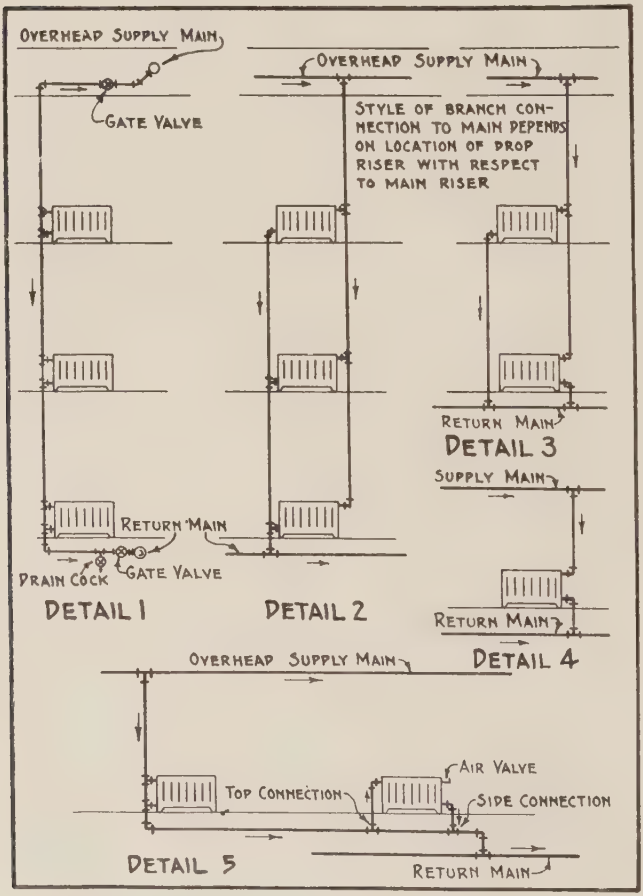


Fig. H-4-2. Drop Riser and Radiator Connections for Down-Feed Gravity Water Heating System

OVERHEAD MAINS—AIR ELIMINATION

In down-feed water heating systems the mains should always pitch down from the high point of the main vertical riser to the last drop riser, as illustrated in Detail 1 of Fig. H-4-3. The attic space in the building of Fig. H-4-1 was such as to permit the installation of the mains in this manner.

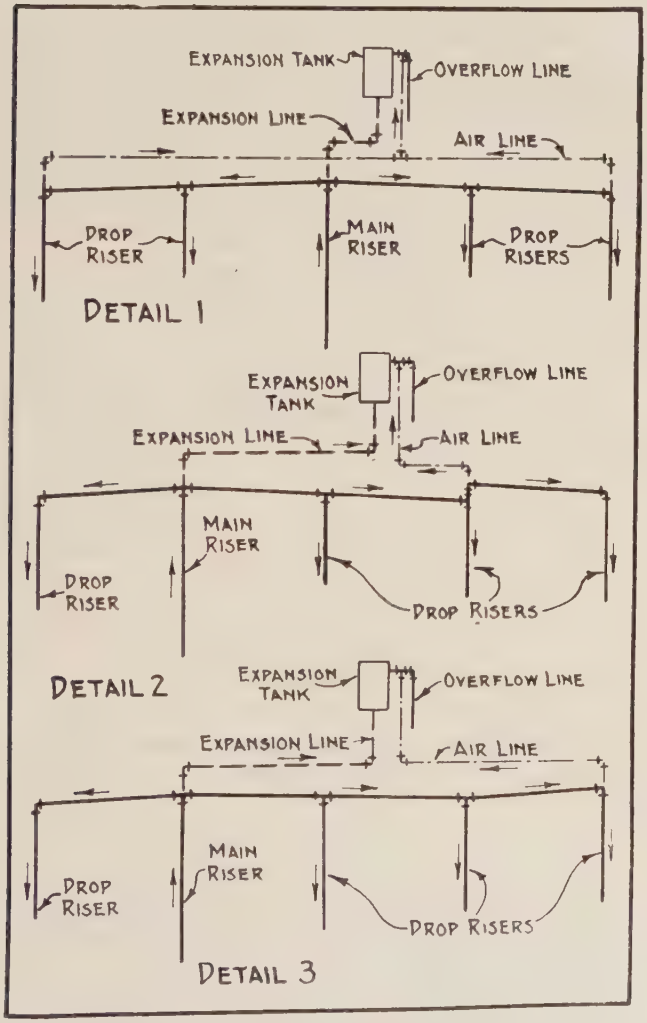


Fig. H-4-3. Runs of Overhead Mains for Down-Feed Gravity Water Heating Systems

A single down-pitch in two directions from the high point of the main riser makes it only necessary to vent the air from the extreme ends of the main. The expansion line connects the high point of the main riser to the bottom of the expansion tank and not only provides an outlet for excess water due to expansion, but also for the air which flows out of the radiators up the drop risers into the overhead main and thence out through the expansion-line connection.

The air line, shown in Detail 1 of Fig. H-4-3, is not generally installed but in the case of a long, low building of this type, such a line assists in removing the entrapped air and permits a cold system to warm up more quickly. It should be noted that the air line is connected to the overflow pipe rather

Work Problem H-4-1

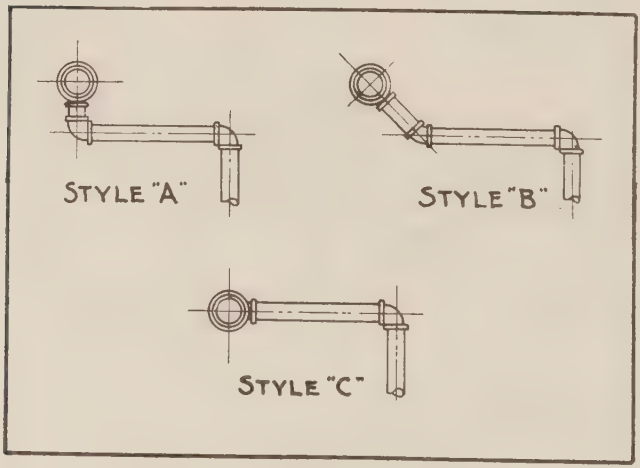


Fig. H-4-4. Styles of Branch Connections to Drop Risers

Work Problem H-4-2

than into the expansion line. This is done in order to avoid any circulation of water through the air line with a resulting unnecessary heat loss. Naturally the air line will be full of water up to the water level in the expansion tank.

When overhead mains are installed in attic space where lack of head room makes it necessary

to step up the main, illustrated in Detail 2, Fig. H-4-3, or to change the direction of pitch, as illustrated in Detail 3, Fig. H-4-3, air lines must be provided to relieve the system. Such air lines are shown in the details mentioned.

BRANCHES FROM OVERHEAD MAINS

It is just as important in an overhead down-feed system of water heating as in an up-feed system that the branch connections to the main be properly made. Three styles of branch connections are shown in Fig. H-4-4.

Style "A" connection is used for making branch connections near the high point of the main riser from the heater by using 90° elbows. This assures improved circulation of the water along the main and avoids a possible short-circuiting of radiators farther along the line.

Style "B" connection is used for making branch connections for drop risers that are located near the center of the supply main for some distance in each direction of the middle of the overhead flow main where the water has become slightly reduced in temperature.

Style "C" connection is used for making branch connections for drop risers located near the end of the main.

Work Problems H-4-3 and H-4-4

DROP RISER CONNECTIONS TO RADIATORS

Various opinions are held as to the best manner in which radiator connections should be made to drop risers in a down-feed water heating system. Several methods are shown in Fig. H-4-2.

Detail 1 of this figure shows the single drop riser, which is generally conceded to be highly satisfactory when not more than three radiators on three different levels are connected to it. Trouble is liable to be experienced when a single drop riser is used in four or more story structures heated by a gravity water heating system.

Detail 2, Fig. H-4-2, shows radiator piping which undoubtedly affords more positive circulation. In proportioning the drop pipes, a reduction is made on the supply side to care for the reduced radiation supplied while the riser on the return side is increased as the lower radiators empty into it. It is believed by some that it is advisable also to connect the bottom of the supply side to the return main with a small pipe so as to assure circulation through the riser in case all radiators are equipped with valves, all of which at times may be closed. Such piping arrangement is shown in Fig. H-1-7. This piping, shown in Detail 2 of Fig. H-4-2, may often be used as a corrective measure for drop risers in which circulation is poor.

Work Problem H-4-5

Detail 3, Fig. H-4-2, shows a piping arrangement which perhaps assures most positive circulation through two radiators on different levels supplied by a single drop riser. With this arrangement, the full size of the drop riser is carried to the radiator and connected into the top with the same-size pipe used as a return connection to the return main. The return from the upper radiator is made to suit the radiation supplied.

Work Problem H-4-6

Detail 4, Fig. H-4-2, shows the usual method of connecting one radiator on a drop riser from an overhead main. When desired, the return connection can be made on the opposite side to the supply.

Work Problem H-4-7

Detail 5, Fig. H-4-2, shows a method of connecting two radiators to one drop riser when the radiators are located on the same level. In this arrangement the supply side of the second radiator should be taken from the top of the horizontal run and the return led into the side of the tee horizon-

COMPRESSION AIR VALVES FOR RADIATORS.

Wood Wheel
Nickel-plated.

Key
Nickel-plated.

Courtesy American Radiator Company.

tally. The second radiator served will require an air valve. Radiators numbered 1 and 2, 9 and 10, 11 and 12, and 13 and 14 in Fig. H-4-1 are connected in this manner.

Work Problem H-4-8

In Fig. H-4-1, certain details of installation, such as the style of branch connection, gate valves, etc., are omitted for the sake of clearness. The following should be observed in planning a system of this kind:

It is advisable to equip each drop riser with a gate valve at both top and bottom and with a drain connection placed inside of the lower valve. See Detail 1, Fig. H-4-2. Thus any drop riser may be emptied for repairs or changes without interfering with the balance of the system. Also, the upper valve may be used to throttle the flow if necessary. Air valves are often placed at or near the top of the drop riser in order that air may be admitted without disturbing a union elbow to assure free flow of the water when both gate valves are closed and the drop riser and radiators drained.

The radiator connections in Fig. H-4-1 are made with swing branch connections where it may be advisable to provide for expansion.

Work Problem H-4-9

APPLICATION OF THE DOWN-FEED SYSTEM TO SMALL INSTALLATIONS

The principle of the down-feed system of water heating has been applied with remarkable success to one and two-story installations without basement.

IDEAL ARCOLA HEATER.

For use particularly in buildings without basement.

Flow pipe tapping, 2-2 in.

Return pipe tapping, 2 in.

These heaters shipped complete in crate. Oval smoke pipe connection for 6 in. diameter pipe.

Courtesy American Radiator Company.

The typical manner of installing a one-story job is illustrated in Fig. H-4-5; a two-story job in Fig. H-4-6. The expansion tank should be located at the highest point of the system. The main supply from the heater is carried directly to the expansion tank from which is taken the supply main for supplying drop risers to the radiators which are piped as indicated in the figures. Sometimes the connections for the supply mains are made as shown in Figs. H-4-7 and H-4-8.

It is important that all piping be properly proportioned if best results are to be secured. The sizes depend upon the location and size of the radiators with respect to one another and to the heater supplying them.

The data in Tables H-4-1, H-4-2, H-4-3 and H-4-4, recommended by the manufacturer of a heater specially built for this type of system, have been used repeatedly by the author with excellent results. While radiators and radiation are covered in detail in a later lesson, it is well to remind the student that when using this down-feed system for a one or two-story installation, with the heater on the

PIPE SIZES

MAINS AND BRANCHES

TABLE H-4-1

MAINS		
No. Sq. Ft. of Radiation	Size Pipe Required	
	First Floor	Second Floor
1	2	3
Up to 150	1¼"	1"
151 to 250	1½"	1¼"
251 to 400	2"	1½"

TABLE H-4-2

BRANCHES When Heater and Radiators are on the same floor	
No. Sq. Ft. of Radiation	Size of Pipe Required
1	2
Up to 30	¾"
31 to 80	1"
81 to 150	1¼"

TABLE H-4-3

BRANCHES When Return from Second Floor Radiator Feeds First Floor Radiator	
No. Sq. Ft. of Radiation	Size of Pipe Required
1	2
Up to 45	¾"
46 to 120	1"
121 to 225	1¼"

TABLE H-4-4

BRANCHES When Return from Second Floor Radiator Flows into Return Main on First Floor.	
No. Sq. Ft. of Radiation	Size of Pipe Required
1	2
Up to 30	½"
31 to 60	¾"
61 to 160	1"

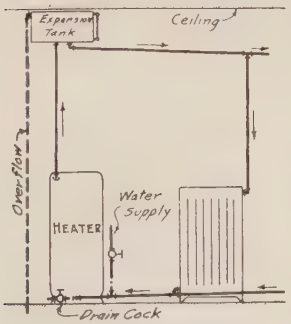


FIG. H-4-5

Fig. H-4-5. Typical Down-Feed System for One-Story Installation

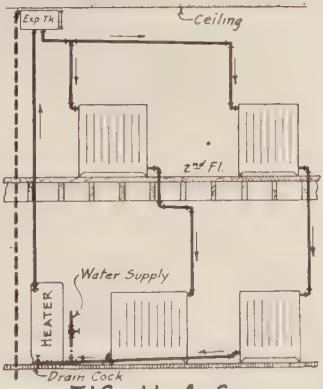


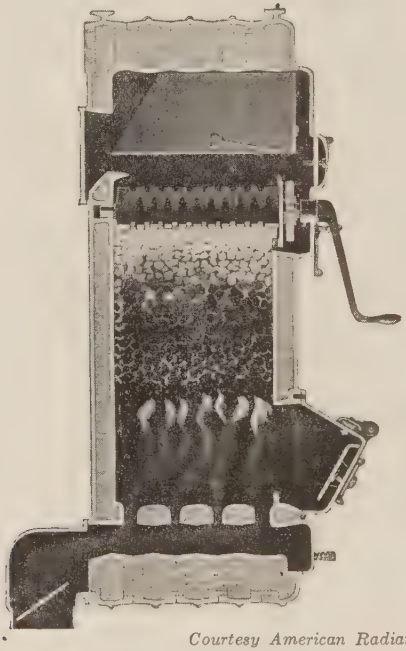
FIG. H-4-6

Fig. H-4-6. Typical Down-Feed System for Two-Story Installation

same level as some of the radiators, better results will be obtained if all radiators used are not less than 38 in. high.

IDEAL ARCOLA HEATER.

Cross section showing water surrounded ash-pit, fire travel and up-looking smokehood.
Suitable for heating structures with or without basements.



Courtesy American Radiator Company.

The capacities and dimensions of a heater suited to this system as marketed by one manufacturer are illustrated and given in Table H-4-5 and sketch directly below. The length and depth of the heater will depend upon the number of sections comprising the heater. The side view in Fig. H-4-9 shows a heater of five sections. Two interior sections have been partly removed to show the location of grate, ash-pit and interior heater section. These heaters may be obtained with from four to eight sections inclusive. The square feet of direct radiation which they will supply is given in Table H-4-5. The note directly below this table should be observed when making a selection.

Work Problems H-4-10, H-4-11, H-4-12, H-4-13, H-4-14

STRAIGHT-RUN TWO-PIPE UP-FEED SYSTEM

Perhaps the most usual type of water heating system installed in residences is a straight-run system having usually two supply and two return mains. A typical layout is shown in Fig. H-4-10.

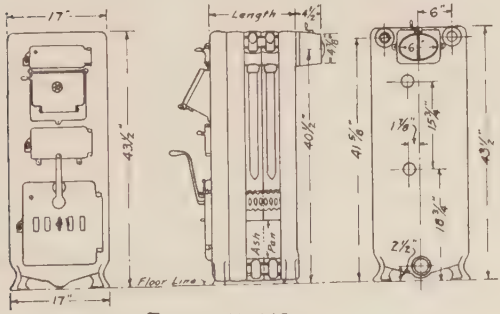
A study of the length of water travel to each of the radiators shows that it differs for each radiator

HEATER CAPACITIES

TABLE H-4-5

No. of Heater	No. of Sections	Rating: Square Feet of Direct Radiation: Nominal	Rating: Square Feet of Direct Radiation: In addition to Piping and Heater Surface: With Hard Coal	Rating: Square Feet of Direct Radiation: In addition to Piping and Heater Surface: With Soft Coal	Fuel Capacity Pounds	Width Inches	Length Inches (over sections)
1	2	3	4	5	6	7	8
1	4	200	135	100	60	17	12
2	5	300	200	150	80	17	15
3	6	400	265	200	100	17	18
4	7	500	330	250	120	17	21
5	8	600	400	300	140	17	24

NOTE:- In figuring the square feet of radiation required for a room in which the heater stands, allow for the heater itself about 20 square feet for No. 1 and 5 square feet additional for each size larger.
Flow and return pipe tapping, 2 inches.
Smoke pipe connection, oval, 6 inches longest dimension



DIMENSIONS

on a run. In many installations this may not be particularly objectionable. In a case, however, where the last radiators served are located on the north side of the building, it may result in lack of sufficient heat being carried to them unless the radiators are increased in area to compensate for

IDEAL ARCOLA PARLOR HEATER.

Cellarless home heater built in attractive design, equipped with automatic heat-control device and of gas-tight construction.

Courtesy American Radiator Company.

Table H-4-6. Dimensions and Ratings.

Number of Boiler	Number of Sections	Water Rating Sq. Ft.	Water Area Sq. Ft.	Hard Coal Fuel Cap. Lbs.	Length "L" Inches	Chimney Size (Sea Level) Inches	Chimney Height Ft.	Radiating Surface of Arcola and Exp. Tank Sq. Ft.
40	4	375	0.81	66	17	8 x 8	25	45
50	5	500	1.08	88	20½	8 x 8	25	50
60	6	625	1.35	110	24	8 x 8	30	55
70	7	750	1.62	132	27½	8 x 8	30	60

Tappings—One 2½-inch outlet and one 2½-inch inlet.

the lower average temperature carried therein. It should be noted in connection with Fig. H-4-10 that the length of water travel through radiators A and K is short, while that through radiators E and F is relatively long. A comparison of the length of water travel to and from each radiator shown in Fig. H-4-10 with that to each of the radiators shown in Fig. H-1-11 clearly shows the advantage possessed by the run illustrated in Fig. H-1-11.

Work Problems H-4-15 and H-4-16

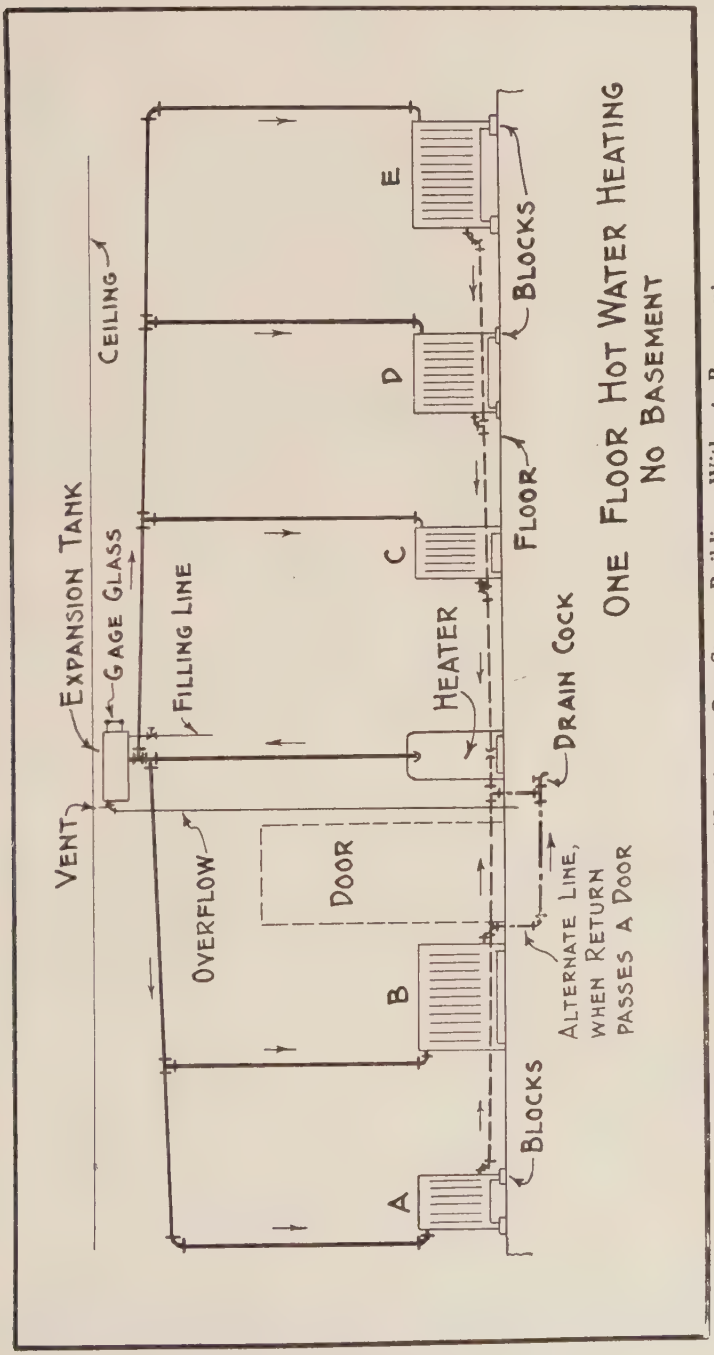


Fig. H-4-7. Layout for Heating a One-Story Building Without Basement
(*Used with assigned Problem H-4-12*).

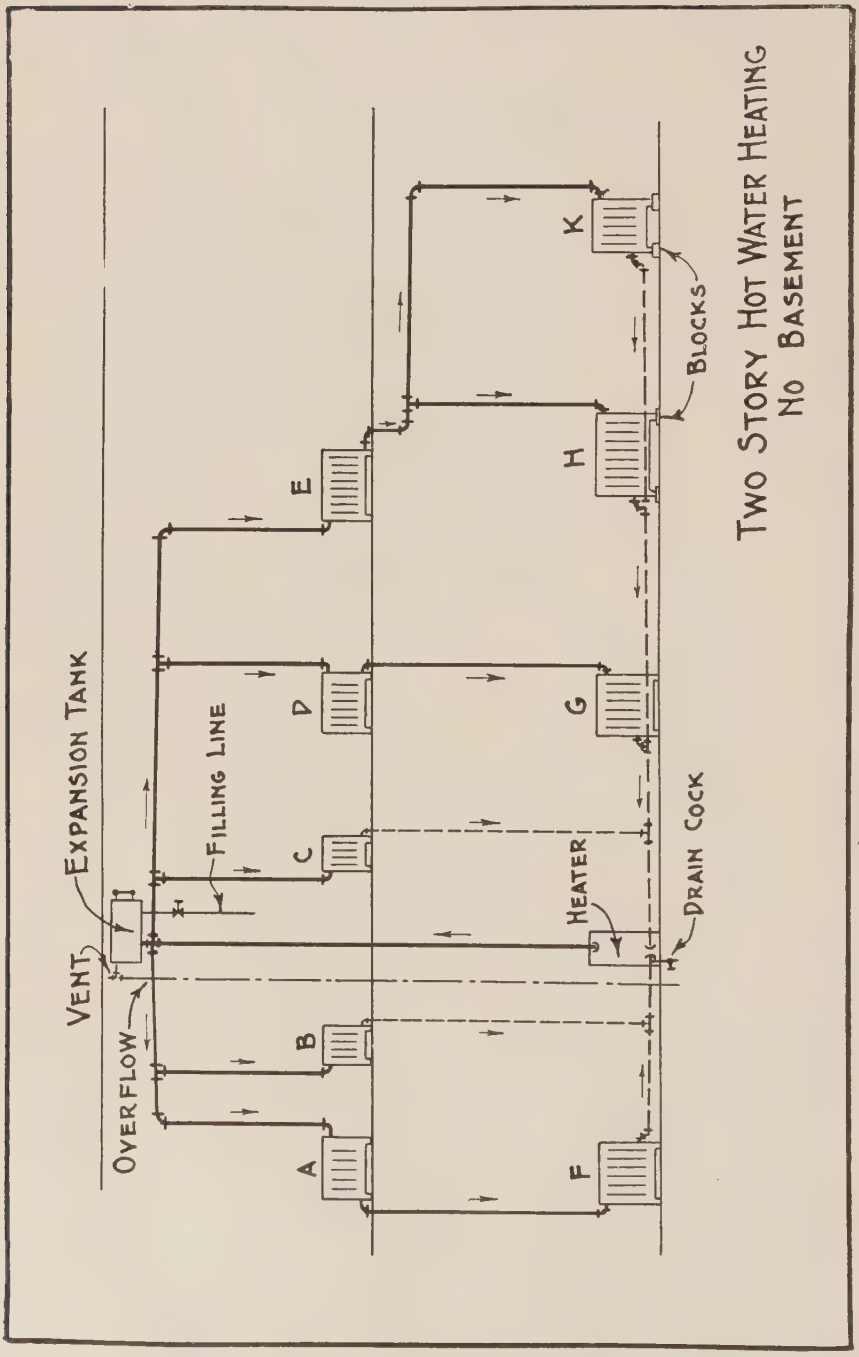


Fig. H-4-8. Layout for Heating a Two-Story Building Without Basement
(Used for assigned Problem H-4-13).

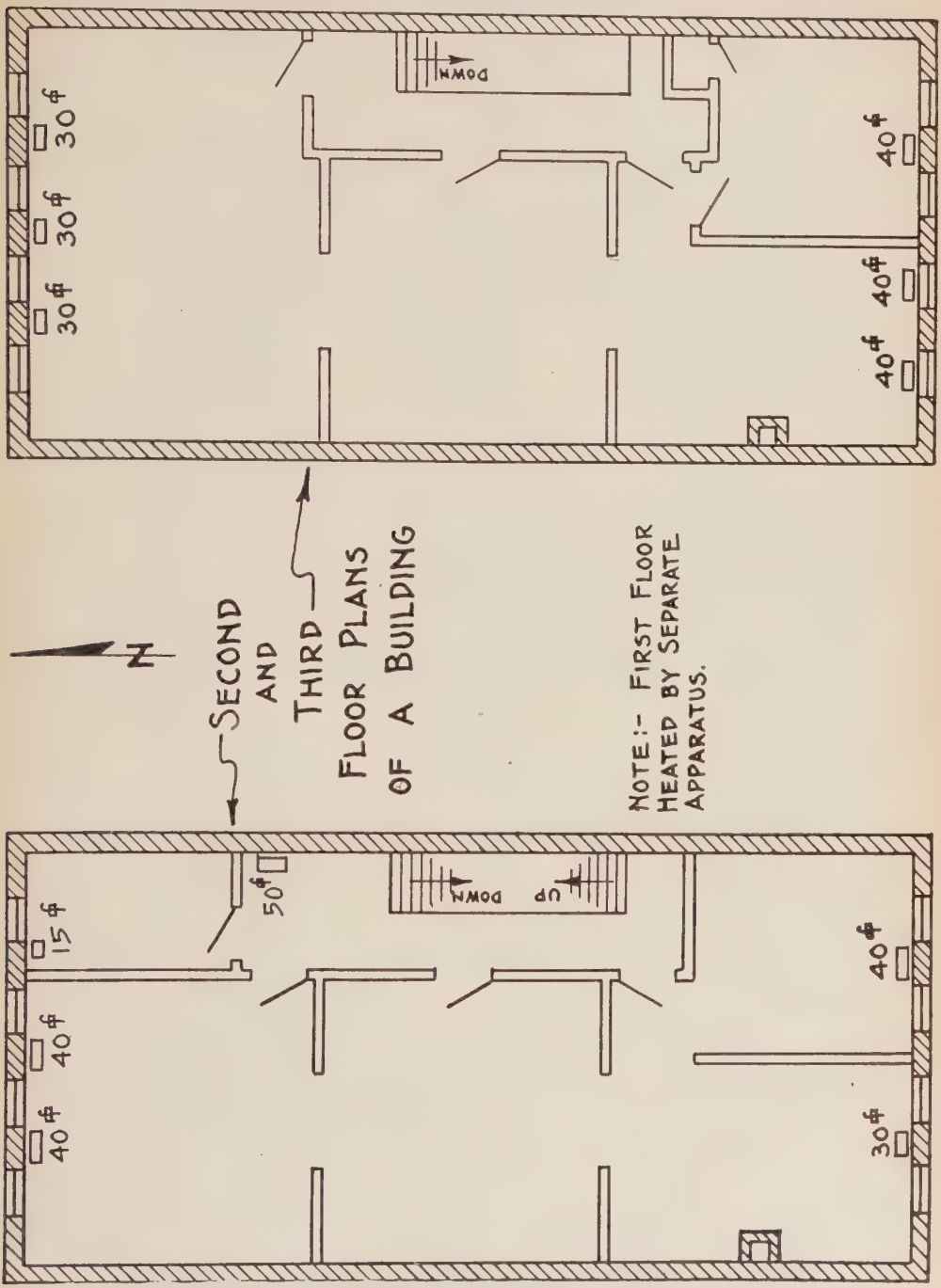


Fig. H-4-9. Plans of the Upper Floors of a Building for Which a Piping Diagram is to be Prepared and Heater Selected. Lower Floor Separately Heated.
(Used with assigned Problem H-4-14).

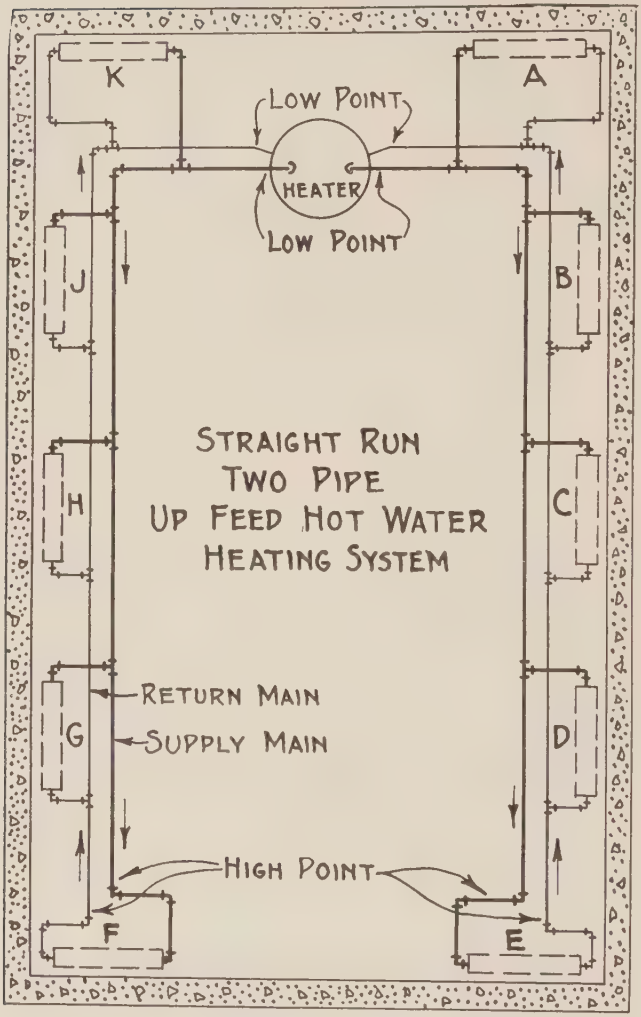


Fig. H-4-10. Straight Run Two-Pipe Up-Feed Water Heating System

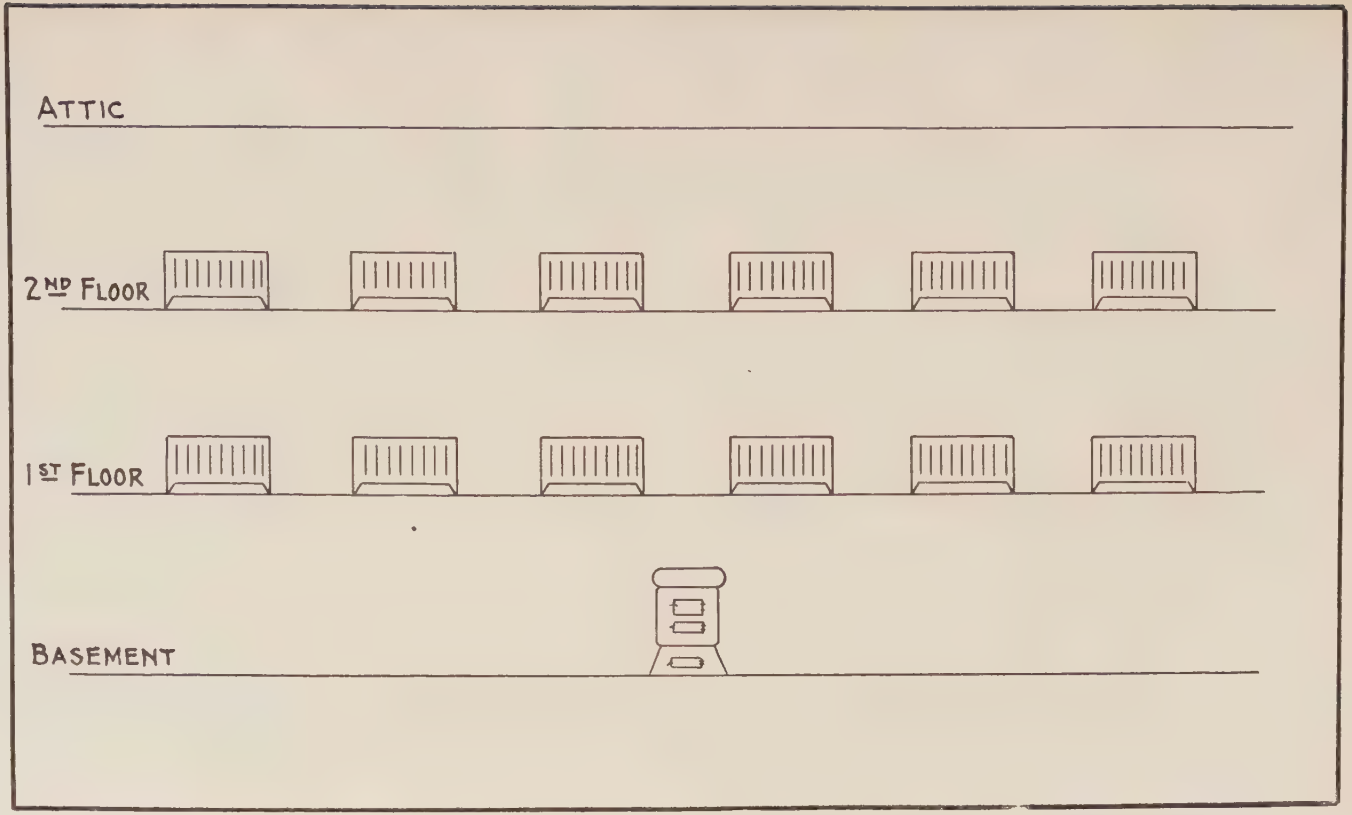


Fig. H-4-11. Radiators and Heater to be Piped up for Heating by Four Different Water Heating Systems.
(Used with assigned Problem H-4-15).

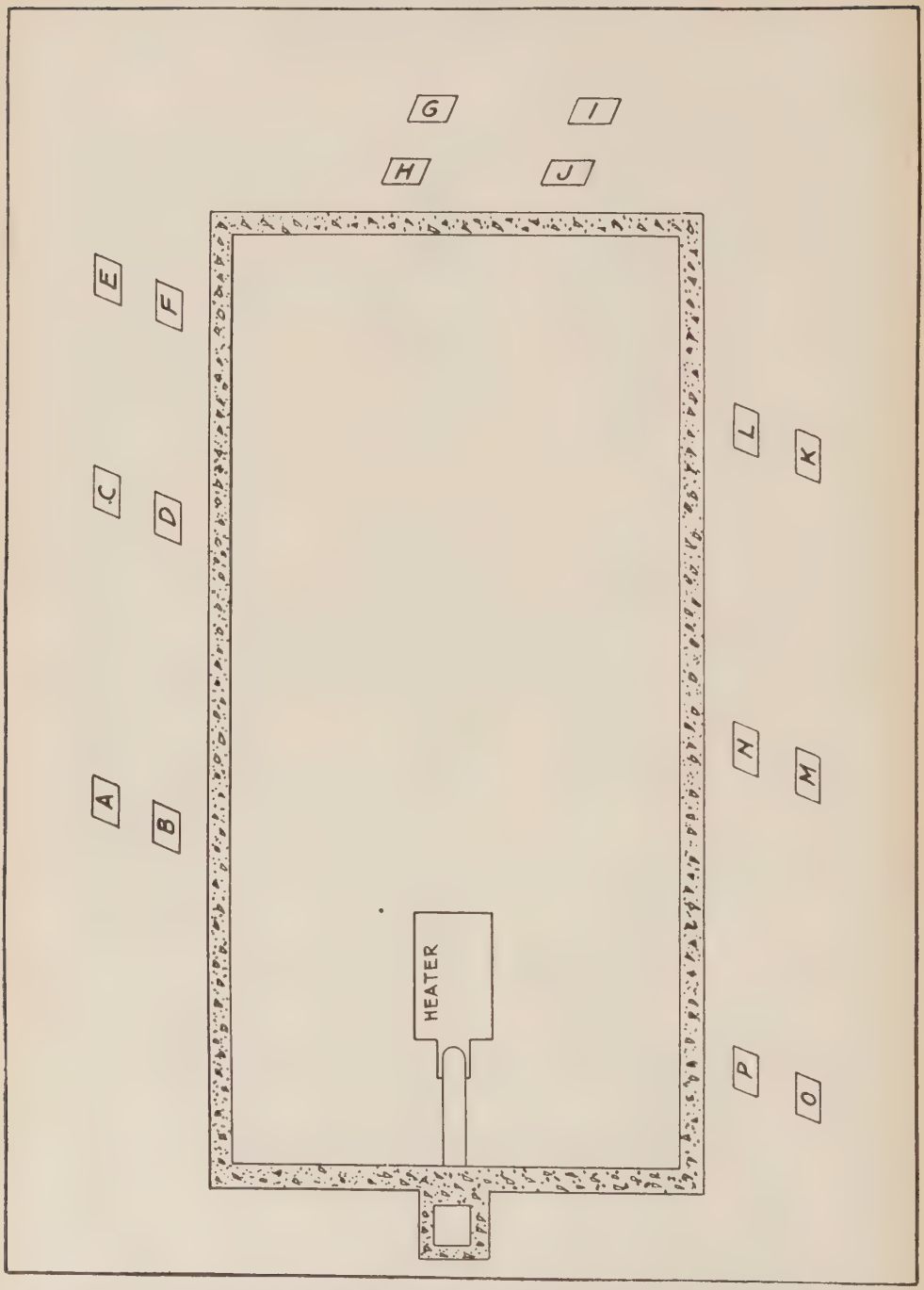


Fig. H-4-12. Basement Plan With Sixteen Radiators on Two Floors for Which Two Different Water Heating Systems are to be Designed.
(*Used with assigned Problem H-4-16*).

PART H.

HOT WATER HEATING

LESSON 5.

Single Main Circuit System

GRAVITY

WATER HEATING SYSTEMS

SINGLE-MAIN CIRCUIT SYSTEM

The two-pipe circuit system of water heating is somewhat similar to the one-pipe up-feed system illustrated in Fig. H-3-1. A typical layout for the circuit system is shown in Fig. H-5-1. In this system the main is carried around the basement ceiling until the return riser from the last radiator served enters as at point A, Fig. H-5-1. The main is then dropped and enters the boiler at the low point of the system. Or, it may be carried to a point directly over the boiler and then dropped to the boiler return connection.

This single-pipe circuit basement main is graded up from the boiler outlet, point B, to the last riser connection, as at point A. When in operation, friction in the main assists the circulation into supply risers.

In designing and installing this system, it is important that each supply riser should be taken from the main as near the boiler supply outlet as convenient, as at point C, Fig. H-5-1, and that the return drop-riser connection be made at a point as far removed from the supply connection as possible, as at D, Fig. H-5-1.

The friction in the pipe between the supply tee and the return tee, although slight, results in a little greater tendency for the water to flow into and up the supply riser than for it to pass along the main. Consequently, the farther apart these connections are made, the greater will be the tendency of the water to circulate through the radiators. This fact should be carefully observed in planning this type of system.

The main should be carried full size throughout the entire circuit, that is, from point B to point A, Fig. H-5-1. It should be proportioned to carry the total radiation load. Theoretically and practically, too, the main might be reduced between radiator supply and return connections since some of the water is shunted through the radiator. In fact, it is good policy to reduce the main between such points in order to assure more positive circulation to and from the risers.

All supply branch connections should be taken off the main with a Style B (See Fig. H-2-2) connection and all return risers should be made with a Style C connection. The proper connections are also shown in the upper left corner of Fig. H-5-1.

Reasonable satisfaction may be expected from a circuit-main system of small size, but its use is not recommended for the larger installations. Full-size radiator tappings should be used. Pipes may be proportioned from Tables H-1-3 and H-1-1 or Table H-1-2. It is often advisable to increase the required area of radiators near the end of the main by 10% to compensate for the somewhat lower temperature of the water supplied them.

Work Problem H-5-1

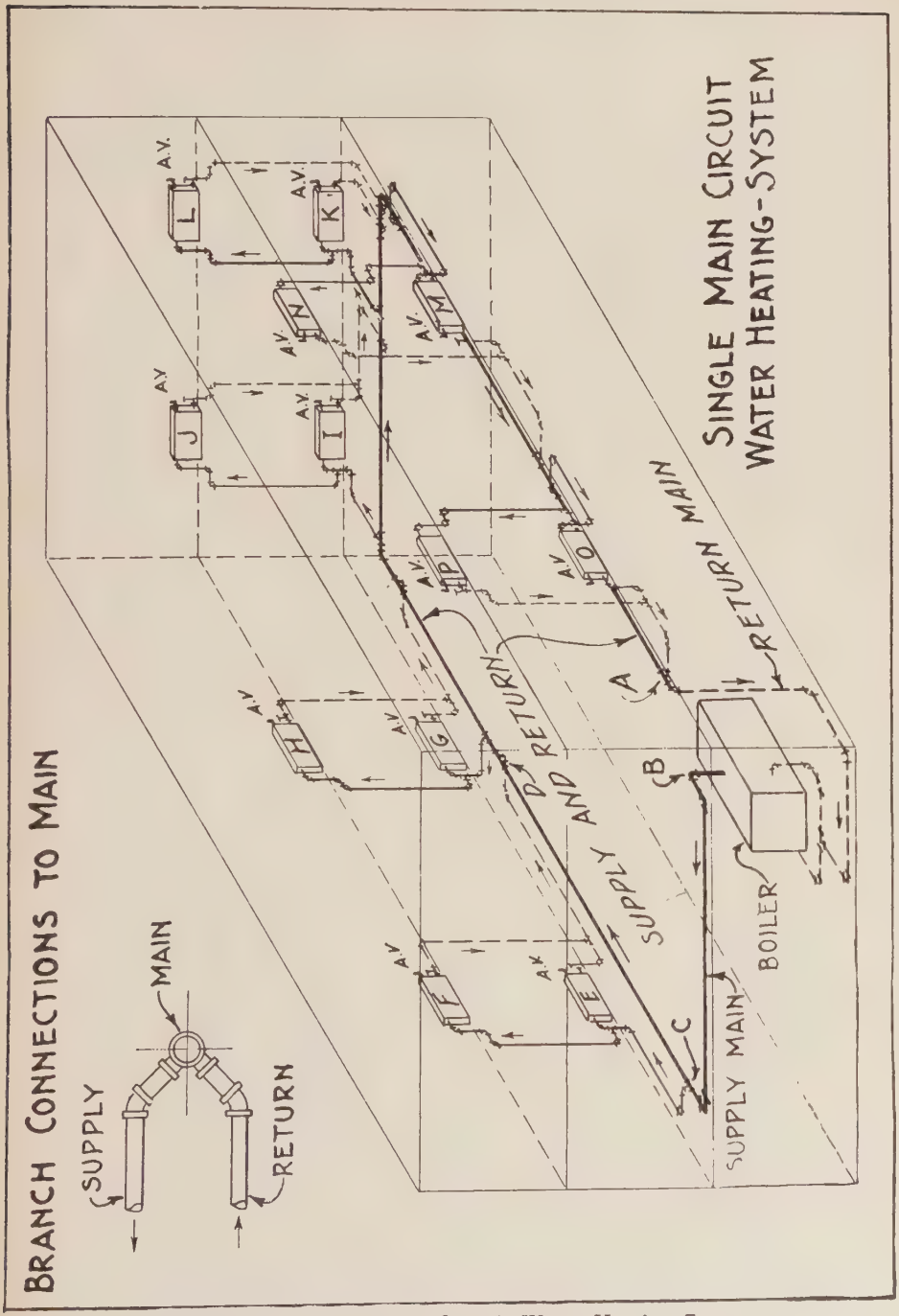


Fig. H-5-1. Single Main Circuit Water Heating System

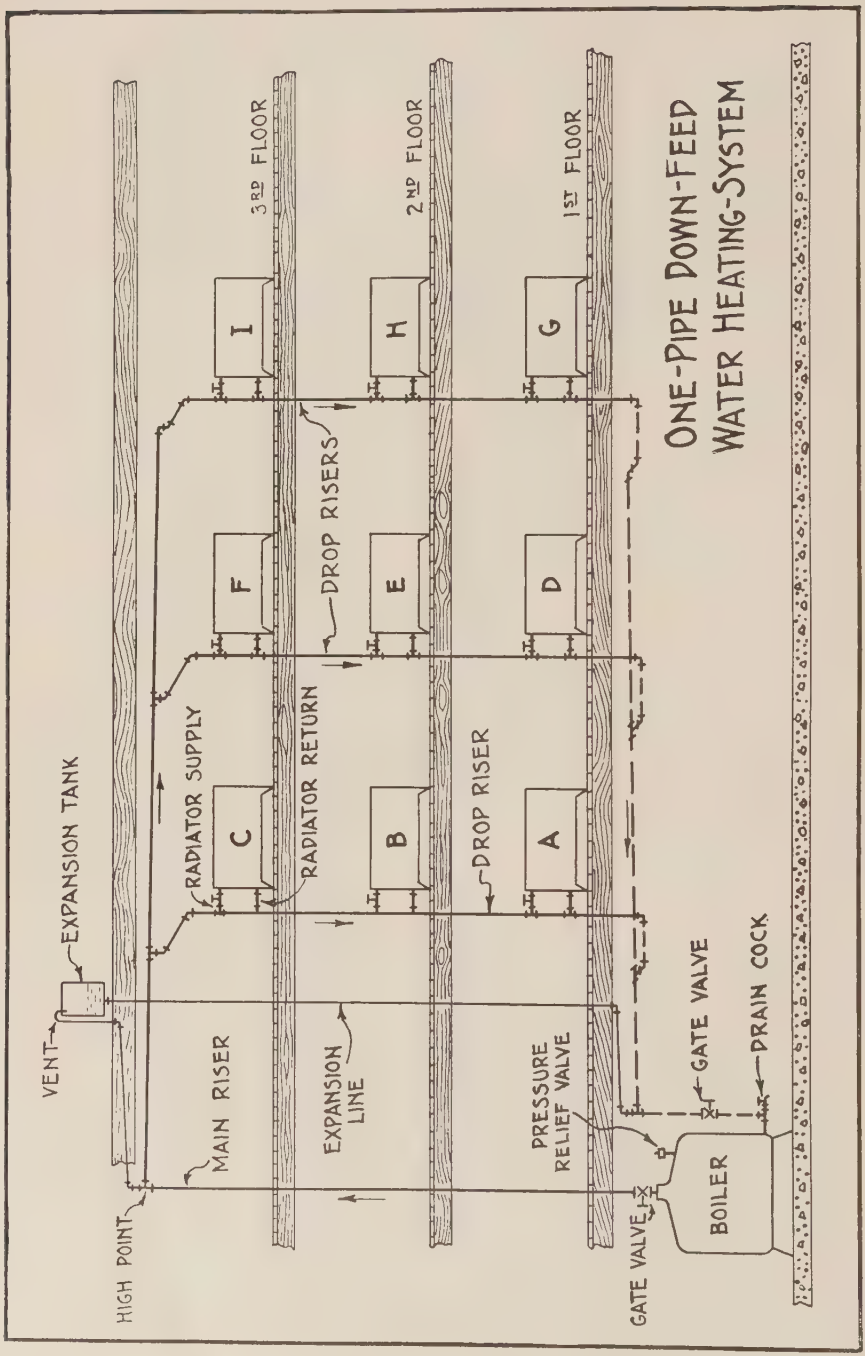


Fig. H-5-2. Typical One-pipe Down-feed Water Heating System.

ONE-PIPE DOWN-FEED SYSTEM

A typical layout of strictly a one-pipe down-feed gravity water heating system is shown in Fig. H-5-2. The layout shown in Fig. H-4-1 was an adaptation of this system to a rather unusual condition.

In order that this one-pipe down-feed system may function properly, it must be installed as shown with an overhead supply main and a low return main. The radiators are tapped top and bottom usually with tappings on the same end, as shown in Fig. H-5-2, or the return may be taken out the opposite side from the supply.

It is best to reduce the size of the drop riser between the supply and return tees to the radiator in order to assure more positive shunting of part of the flow through the radiator. Generally, this is not done. The circulation will usually be satisfactory because the unit weight of water in the radiator is greater than that in the riser which is caused by a cooling and contracting of the water in the radiator. A reduction in the size of riser will much improve the circulation.

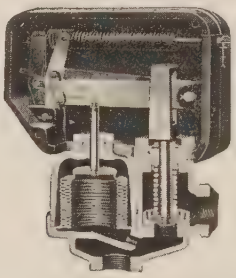
No air valves are necessary with this system for small and medium-size installations. For large jobs, such as that shown in Fig. H-4-1, they should be used as explained. The system is vented to the high point from where a vent pipe is carried to an expansion tank.

The temperature of the water in the drop constantly decreases. In a building of considerable height, this reduction of temperature in the supply, caused by the dumping of cooled water into the drop riser from radiator returns, may be serious enough to require increased radiating surface for the lower radiators in order to compensate for the cooler water delivered into them. This condition constitutes the chief objection to the wider use of this system.

In order to prevent damage to the boiler, in case valves on both supply and return mains are closed at the same time, a relief valve should be placed on the boiler.

This system of heating by gravity water circulation is probably the cheapest of any of the methods of piping such a system but is not as satisfactory as a properly-designed two-pipe system where supply risers convey only supply and return risers only return water.

WATER RELIEF VALVE.



Courtesy American Radiator Company.

Suited to hot water heating boilers and hot water supply systems. Increased power obtained by lever action is claimed to be sufficient to overcome any sticking of the valve seat due to corrosion. Valve automatically re-sets as pressure decreases. Relieving pressure regularly furnished for heating boiler: Primary 30 lbs., Emergency 40 lbs., Height 10½ ins., Width 9¼ ins., Size 1 inch.

PROPORTIONING PIPES

In proportioning the mains and radiator connections, the branch size to each radiator is first determined. The exceedingly low head available between the top and bottom radiator connection, as explained above, requires the use of full-size standard radiator tappings for the run out and valve in order to assist circulation to and from the radiator as much as possible. The size of radiator valve and return connection may therefore be taken from Table H-5-1.

Work Problem H-5-2

The size of risers may be developed from sizes of radiator valves and return connections, using Table H-1-1 or H-1-2. The main also may be proportioned by using either of these tables.

Work Problem H-5-3, H-5-4

TABLE H-5-1
STANDARD RADIATOR TAPPINGS
WATER RADIATORS
TAPPED FOR SUPPLY AND RETURN

RADIATOR SIZE	TAPPING SIZE
UP TO 40 SQ. FT. INCLUSIVE	1" AND 1"
ABOVE 40 SQ. FT., UP TO 72 SQ. FT.	1¼" AND 1¼"
ABOVE 72 SQUARE FEET	1½" AND 1½"

DETERMINING RISER SIZES BY HEIGHT OF RADIATOR ABOVE BOILER FOR ANY SMALL GRAVITY WATER HEATING SYSTEM

Circulation of water in a riser of any water heating system is governed by two factors, the height of the riser and the temperature of the water therein. The size of the radiator return connection does not govern, but influences, the circulation. The cooling effect of the radiator is the great influencing factor, for this lowering of the temperature, with consequent increase in specific density of the water, causes circulation—with no cooling effect there would be no circulation.

Therefore, if, in the problem assigned for Fig. H-5-2, all radiation on each drop riser were located the same distance above the boiler, the size of the drop riser could be taken directly from Table H-5-2.

This table shows the amount of equivalent direct radiation that can be supplied satisfactorily at the elevation above the boiler, as given at the top of each column. The elevation is measured from the horizontal center-line of the heater to the horizontal center-line of the radiator. Thus, for 250 sq. ft. of radiation located 5 ft. above the boiler center line, a 2-in. pipe is required, whereas if this amount of radiation were located 50 ft. above, a 1½-in. pipe would be ample.

Work Problem H-5-5

The average temperature of the water in a riser will determine the riser size. This can be found by determining the equivalent elevation at which all the radiation might be placed to produce the same effect. This may be done as follows:

First: Multiply the area in square feet of each radiator by the vertical distance in feet that it is located above the boiler. This should be done for each radiator.

Second: Add all these products and note their sum.

Third: Determine the total radiating surface of all radiators fed by a given drop riser.

Fourth: Divide result SECOND by result THIRD and obtain equivalent distance in feet of all radiation above the boiler for a particular riser.

Fifth: Refer to Table H-5-2 and select the proper size riser for the total radiation (result THIRD) when located at the average elevation (result FOURTH).

Work Problem H-5-6

TABLE H-5-2
HOT WATER PIPE SIZES
FOR
SMALL GRAVITY SYSTEMS

DIAMETER OF PIPE AND SIZE OF RADIATOR VALVE - INS.	HEIGHT OF ℄ OF RADIATOR ABOVE ℄ OF BOILER								
	5	15	25	35	45	55	65	75	85
¾	40	50	60	70	80	90	100	110	120
1	70	80	90	100	110	120	130	140	150
1¼	110	117	135	147	170	187	205	222	240
1½	180	195	210	230	245	260	275	295	310
2	300	375	450	500	575	650	700	777	850

EXPANSION TANKS AND CONNECTIONS FOR OPEN-TANK WATER HEATING SYSTEMS

As the temperature of water is raised, its volume increases—as the water cools, its volume decreases. Consequently, in a water heating system provision must be made to care for the expansion and contraction of the water. Steel tanks, commonly called expansion tanks, are used for this purpose. They have been included in the typical layouts of the different types of systems covered in previous lessons.

SIZE OF EXPANSION TANK REQUIRED

The size of the expansion tank depends upon two factors: (1) the amount of water in the system, (2) the range in temperature through which the water may pass from a cold to a hot system.

If the temperature of a given weight of water be raised from 32° to 212° F., its volume will increase approximately 4.33%, that is, the volume of a given quantity of water at 212° F. will be about 1/23 greater than its volume at 32° F. Thus, for every 23 gal. of water in a water heating system when the system is cold (assumed at 32° F.), there should be an allowance of 1 gal. in the expansion tank when the system is hot (assumed at 212° F.).

Work Problem H-5-7

VOLUME OF RADIATORS AND PIPE

Cast-iron radiators have an internal volume of about 1½ pints per square foot of radiating surface. Steel radiators and 1-in. pipe hold about 1 pint per square foot of radiating surface.

It may be assumed safely that the internal volume of the radiators in a water heating system is about 50% of the volume of the entire system including piping, radiators and boiler. On this assumption, a system consisting of 2400 sq. ft. of direct cast-iron radiation would have a capacity of 2400 (sq. ft.) × 2 (50% total capacity) × 1½ (pints per sq. ft.) = 7200 pints or 900 gallons.

Work Problem H-5-8, H-5-9

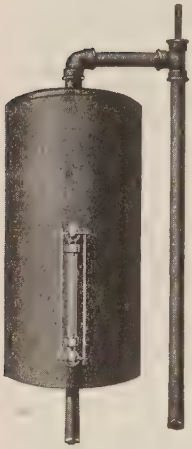
If the water contained in the system of the above example were to be heated from 32° to 212° F., the increase in volume (in gallons) would be 900 (gal.) ÷ 23 (proportional increase) = 36 gal. (appx.).

Work Problem H-5-10

For practical reasons, the capacity of expansion tanks should be made somewhat larger than the theoretical volume required. The tank for a given system should be not less than 25% in excess of that figured as explained above. Therefore, the

capacity of the tank for a system in which the increase in water volume is 36 gal. would be 1.25 × 36 = 45 gal. capacity.

Work Problem H-5-11

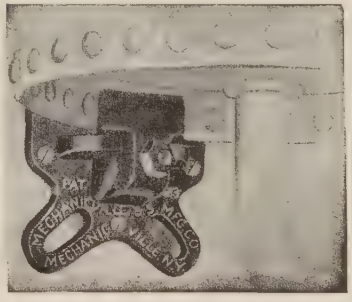


Expansion Tank. Steel—Galvanized. Overflow and Expansion tappings — 1 inch. Water gage tappings—½ in. on 13½ in. centers.

Courtesy American Radiator Company

EXPANSION TANK BRACKETS.

Courtesy American Radiator Company.



Courtesy United States Radiator Corp.

Table H-5-3 contains capacity sizes and rated radiation capacity for stock expansion tanks. These tanks are made of steel, heavily galvanized. They are tapped top and bottom generally 1-in. for overflow and expansion lines and on the side for a feed pipe. Water-gauge tappings on the side are usually ½-in. on 13½-in. centers.

Work Problem H-5-12

TABLE H-5-3 EXPANSION TANK SIZES

NO.	SIZE - INCHES		GALLONS	SQUARE FEET OF RADIATION DIRECT
	DIAMETER	HEIGHT		
0	10	20	8	250
1	12	20	10	300
2	12	30	15	500
3	14	30	20	700
4	16	30	26	950
5	16	36	32	1300
6	16	48	42	2000
7	18	60	66	3000
8	20	60	82	5000
9	22	60	100	6000

In Fig. H-5-3, various methods for piping expansion tanks are shown. Detail 1 of this figure shows the connection of the expansion tank for a one-pipe up-feed system. (See also Fig. H-3-1.) The open tank should be installed at a suitable elevation with the bottom of the tank at least 3 ft. above the top of the highest radiator. (See details 2 and 3, Fig. H-5-3.) It is well to connect the expansion line to the nearest return riser, as shown in Detail 3. Preferably, a separate expansion line is run to the flow or return main in the basement, as shown in Fig. H-3-1.

In small installations, principally residential plants of only moderate size, the expansion line is connected to the return riser of one of the highest radiators and no overflow other than the vent is provided. Unless extreme economy is required, this method is not advised as it is distinctly a cheap method. When connections are made as in Detail 3, Fig. H-5-3, no means are provided for circulation and it is necessary that the expansion tank be located in a space where there will be no danger from freezing temperatures. The vent or overflow usually is discharged upon the roof.

Work Problem H-5-13

Detail 4, Fig. H-5-3, shows a quite general method of connecting up the expansion tank and the highest radiator nearest it. The connection to the bottom of the tank is taken from the return riser.

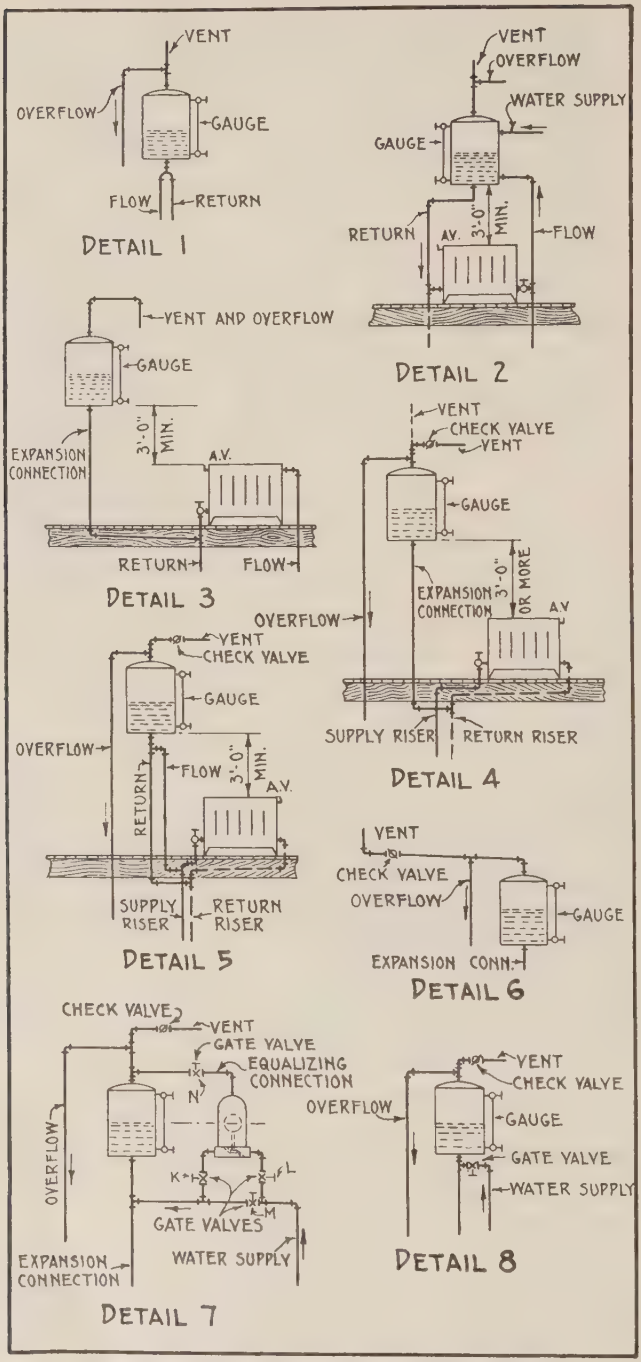


Fig. H-5-3. Expansion Tank Connections.

An overflow connection is taken off the top from the side outlet of a tee and led downwards. The vent connection, shown as a dotted line, is carried directly upwards. This vent prevents the system from siphoning out when it is overflowing for, by being located at the extreme top of the system, air is admitted as soon as a suction is established by the downward moving current of water in the overflow.

This method of connections presents two possible sources of trouble: (1) the vent or overflow connection, if open directly to the outside atmosphere results in serious damage to the boiler in case the exit of either pipe becomes blocked by freezing; (2) the overflow pipe, if run to some convenient toilet fixture near the tank (and this is not unusual) may result in continuous wastage of water in case the water supply valve is defective or is not fully closed.

This overflow line should always be carried to the basement and discharged near a floor-drain above the floor line when such a drain exists. Thus any defect that may develop in the water supply valve will be known by the flow of water.

The better method for making the vent connection is to use a check valve of the "swing" type, shown by full lines, with the gate opening inwards. This will prevent water from escaping if it should happen to boil violently and will open instantly and admit air should siphoning begin.

Work Problem H-5-14

It is always preferable to locate the expansion tank in a heated space, but in case it is not so placed (sometimes it is installed in an unheated attic space) the tank should have an insulating covering applied. It should also have a circulating connection to guard against the possibility of freezing. Detail 2, Fig. H-5-3, shows one method of connection. In using this method, the supply connection should be made on the side as near the bottom as possible. Detail 5, Fig. H-5-3, however, shows a better way to make the connections and is particularly suited to tanks that have only top and bottom tappings.

Work Problem H-5-15

Expansion-tank connecting piping need not be large. For installations up to 1000 sq. ft. of radiation, a ¾-in pipe is ample for expansion and overflow lines. This size should be increased by one pipe size for every 1000 sq. ft. of radiation in excess of the first 1000 sq. ft. This proportion may apply up to 5000 sq. ft. Above this amount, the increase should be one pipe size for every 2500 sq. ft. in excess of 5000 sq. ft.

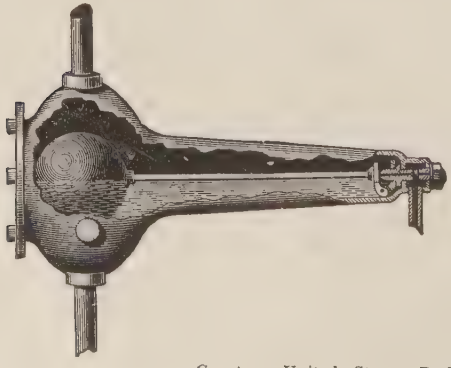
The "swing" check valve on the vent or siphon-breaker line should be ½ in. for installations up to 1000 sq. ft. For larger installations, it should be made one-half the diameter of the expansion and overflow pipe.

Work Problem H-5-16, H-5-17

Detail 6, Fig. H-5-3, shows a connection often employed in cold climates. This vent and overflow connection is used where there is a liability of the vent line freezing (if run out through the roof) caused by the condensation and vapor as it passes out through the line becoming cooled and finally freezing. Most of the vent line should be kept within the building and to assure this it is installed only 2 ft. high above the tank. It is equipped with a check valve to prevent the escape of water through it in case the tank should overflow suddenly. When the check valve closes, the excess water will pass down the overflow and prevent any flooding.

Work Problem H-5-18

AUTOMATIC WATER FEEDER.



Courtesy United States Radiator Corp.

AUTOMATIC WATER-FEEDER FOR HOT WATER SYSTEM

Detail 7, Fig. H-5-3, shows an expansion tank and connections including an automatic water-feeder. This is a desirable addition to any water heating system. By its use the water is maintained at the desired level in the tank without attention. If the radiators are periodically vented and no automatic water-feeder is installed, the addition of make-up water may become bothersome. In addition to the water regulator, its inclusion requires also four gate valves and a little more piping. Valves K, L, and M are by-pass valves. Normally, valve M remains closed, with K, L and N open. If the feeder is disconnected for examination and repair, these three valves are closed and the system is fed through valve M. The height of the water-line in the tank is governed by means of the equalizing connection line containing valve N.

Work Problem H-5-19

Detail 8, Fig. H-5-3, shows connections for feeding water into the system with the automatic feature eliminated. This arrangement should always be used when the heating system is fed by a pump directly from a well or cistern so that any air entrained in the water can escape directly into the overflow. It is especially convenient to have two feed connections to the system, one at the tank and one at the boiler. This double arrangement permits filling either at the top floor by watching the gauge-glass on the tank or at the boiler by using the altitude gauge as a guide.

Work Problem H-5-20

INSPECTION REPORTS

The student has now progressed to the point where he should be able to determine the cause of trouble with water heating systems that do not function properly and to make a report of how to apply correction methods. There will be presented, from time to time, examples of plants that demand an inspection and the application of remedial meas-

ures. The first such layout is shown in Fig. H-5-4. In this figure is shown a layout of an open tank, water heating apparatus, for a two-story residence and a garage located 40 ft. from the house. Apparatus was installed as shown but worked unsatisfactorily. Radiator K did not heat well. This was due to a short circuit, the water passing up through the risers to radiator J and returning into the return pipes so fast as to establish a reverse circulation in the end radiator. On the other run, radiator D did not heat, the hottest water was in its return pipe instead of being in the supply pipe. The student will make a report on the cause of the trouble and suggest two means for overcoming the difficulty.

Work Problem H-5-21

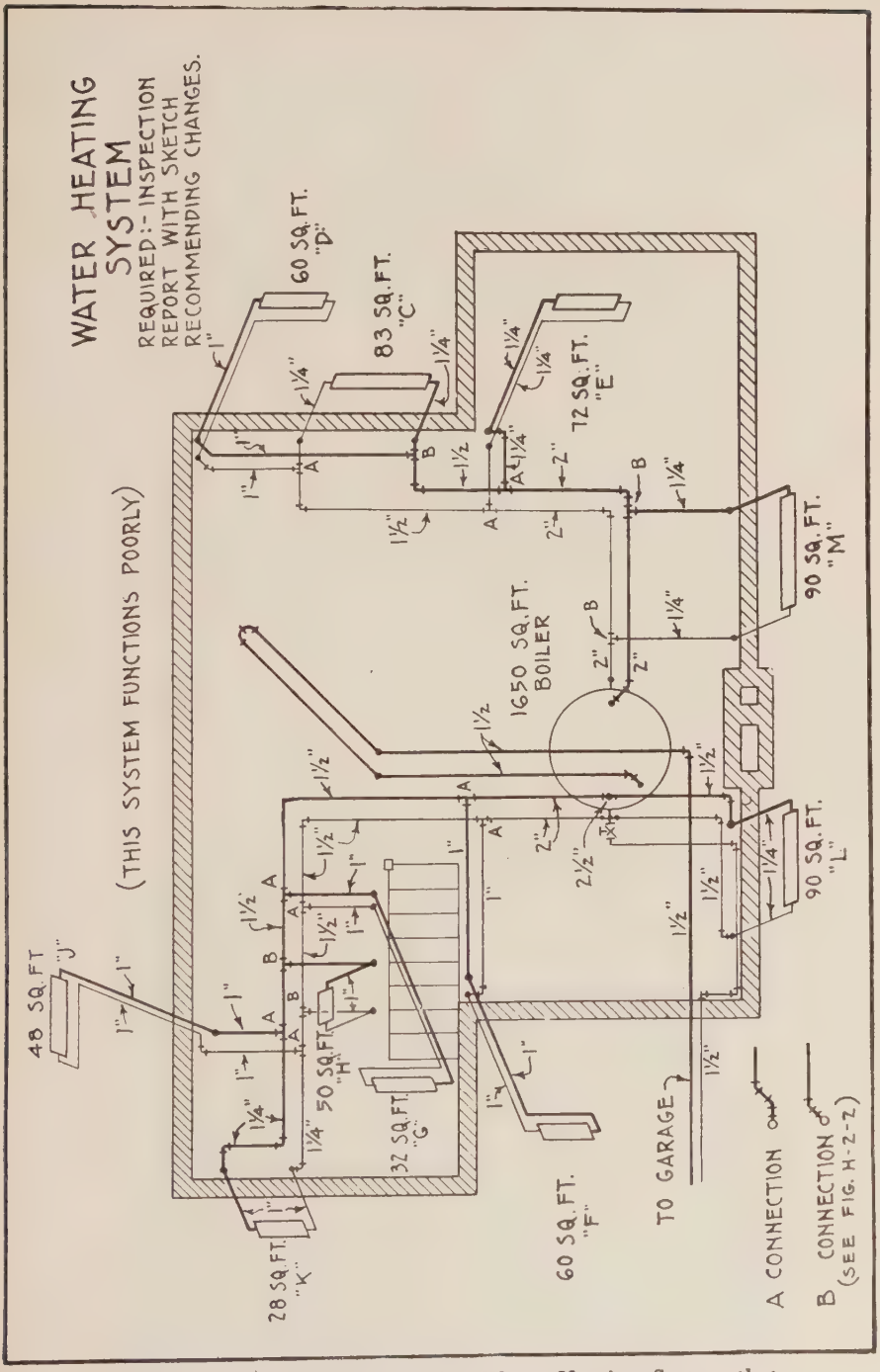


Fig. H-5-4. Basement Plan of a Water Heating System that Functions Poorly. An Inspection Report with Recommendations is Required on This Layout.

PART H.

HOT WATER HEATING

LESSON 6.

Accelerated Gravity Systems

ACCELERATED GRAVITY

WATER HEATING-SYSTEMS.

In the first lesson of this course, devoted to Fundamentals of Heating and Ventilating, it was stated that the boiling temperature of water may be lowered by reducing the pressure. Conversely, by increasing the pressure, the boiling temperature of water may be raised. This is the principle on which closed or accelerated water heating systems function.

In Table H-6-1 are given the temperatures at which water will boil when heated under pressures varying by increments of 2 lbs. from atmospheric pressure (14.74 lbs. per square inch absolute) to a gage pressure of 25.26 lbs. per square inch. Thus, while the temperature of water, boiling in an open vessel, is 212.13° F. (usually called 212° F.), if the vessel be closed and the water subjected to a pres-

sure of 25.26 lbs. per square inch, the temperature will rise to 267.2° F. before boiling commences.

When water is heated it expands, as explained in a previous lesson. In an open-type water heating system, the expansion of the water therein does not change the pressure to which this water is subjected (except to a very minor degree, due to increased static head). In a closed system, it is quite different. Expansion of the water results in compression of the air in the expansion tank unless the tank is omitted, thereby requiring that

TABLE H-6-1
RELATION OF BOILING POINT OF WATER TO GAGE PRESSURE

GAGE PRESSURE LBS. PER SQ. IN.	ABSOLUTE PRESSURE LBS. PER SQ. IN.	BOILING POINT °F.	GAGE PRESSURE LBS. PER SQ. IN.	ABSOLUTE PRESSURE LBS. PER SQ. IN.	BOILING POINT °F.
	14.74	212.13	13.26	28	246.4
1.26	16	216.30	15.26	30	250.3
3.26	18	222.40	17.26	32	254.0
5.26	20	228.00	19.26	34	257.6
7.26	22	233.10	21.26	36	260.9
9.26	24	237.80	23.26	38	264.2
11.26	26	242.20	25.26	40	267.2

TABLE H-6-2
RELATION BETWEEN
HYDROSTATIC HEAD, PRESSURE & BOILING POINT

HYDROSTATIC HEAD - FT.	0	12	24	37	49	61	74	87	100	113	125
PRESSURE - LBS. PER SQ. IN.	0	5	10	15	20	25	30	35	40	45	50
BOILING POINT - °F	212	227	239	250	259	268	274	281	287	292	298

special provision be made to release the expanded volume and replace it when the water cools and contracts; the compression of the air causes increased pressures throughout the system with consequent higher water temperatures.

Therefore the maximum temperature of the water obtainable in any water heating system depends upon the pressure on the system. In an open-tank system, the pressure at any elevation will vary with the distance below the level of the water in the expansion tank. Thus, theoretically, the water in the boiler can be carried at a temperature corresponding to the hydrostatic pressure at

the boiler before boiling will occur. Practically, however, it is impossible to carry water in an open-tank system at a temperature in excess of 212° F. for the high-temperature water will rise into the open tank and boil there where atmospheric pressure exists.

Reference to Table H-6-2 permits a clear understanding of the relation between hydrostatic head or that due to the height of the water in the system, pressure, pounds per square inch, and corresponding boiling point.

Work Problems H-6-1 and H-6-2

The ability to carry a higher water temperature in a closed system without possibility of boiling than in an open system argues well for the closed system of water heating provided all necessary precautions are taken and regularly observed.

Higher water temperature affords greater temperature range, greater flexibility of operation, supplies more heat units per hour per square feet of raditing surface, thereby permitting reduced size of radiators; and causes higher water velocities, thus allowing the use of smaller pipes, fittings and valves.

When a water heating system is sealed, thereby making it a closed system, it is essential that a safety or relief valve be provided, that it be set to operate at a nominal pressure, 10 lbs. per square inch in some systems and as high as 25 to 30 lbs. per square inch in other systems and, that it be examined frequently to see that it operates properly and at the pressure desired.

Special devices or valves are used with closed water heating systems so as to seal the system to the atmosphere and to maintain a pressure on it. The pressure increases until a predetermined value is reached or until the water reaches a predetermined temperature (depending upon the appliance used) when the device operates to break the seal, thereby automatically relieving the pressure and permitting the excess expanded water to pass either to the expansion tank or from the system.

Closed or accelerated water heating systems may be classified generally into three classes:

1. A system in which a special mercury container maintains a predetermined pressure on the system, with expansion tank located either at the high point of the system or in the basement.
2. A system in which a special damper control and relief valve are used to regulate the desired temperature of the water in the system, with expansion tank located either at the high point of the system or in the basement.
3. A system in which a special relief valve and reducing valve are used to maintain the desired pressure on the system and relieve and supply water from and to the system with an expansion tank omitted.

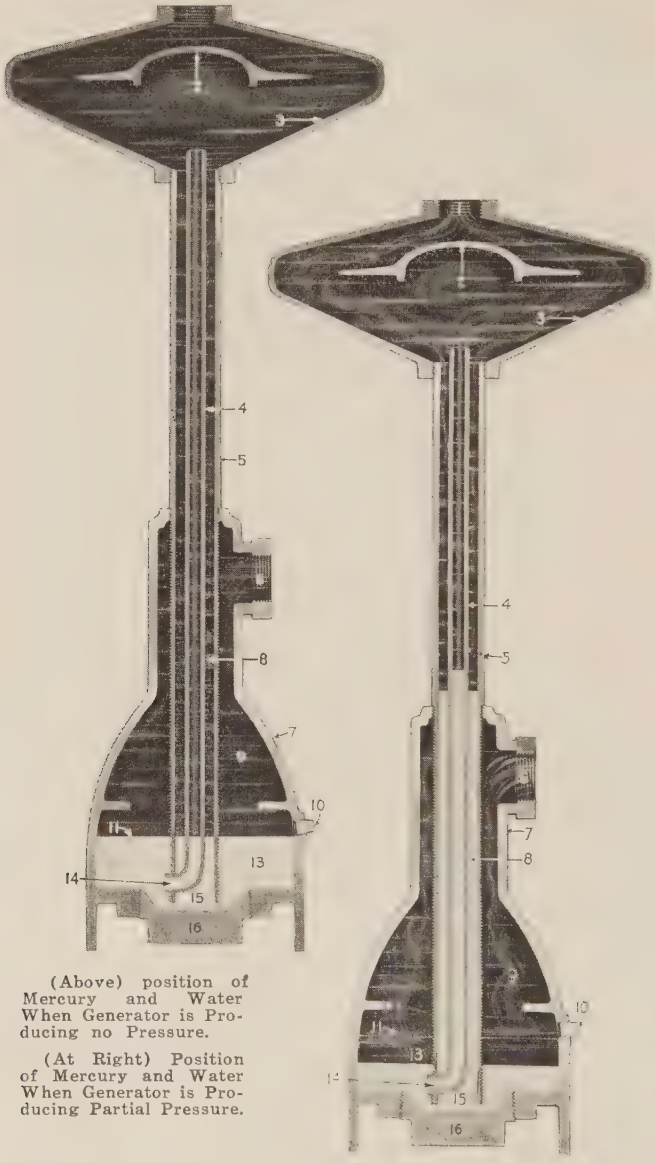
Work Problem H-6-3

MERCURY SEAL SYSTEM

The application of the mercury seal to water heating systems may be clearly understood by reference to Fig. H-6-1 and the following description:

When the water in the system is cold, the mercury 13 (illustrated at left) will all lie at the bottom of the mercury pot 7, about 1 in. in depth, and all other parts of the accelerating apparatus will be immersed in water.

By heating the water it expands and flows through opening 6 into chamber 7. The force of expansion is transmitted through the water volume 9 to the top of mercury 13. This pressure forces some of the mercury through openings 14 and 15, into the circulating tube 4 and stand pipe 5 respectively (see center illustration, Fig. H-6-1). Continued temperature rise of the water results in further expansion with consequent rise of the mercury level in tube 4 and pipe 5 and lowering of the mercury level in the bottom of chamber 7, until the mercury seal at opening 14 is broken (see illustration at right, Fig. H-6-1).



(Above) position of Mercury and Water When Generator is Producing no Pressure.

(At Right) Position of Mercury and Water When Generator is Producing Partial Pressure.

Fig. H-6-1. Mercury Seal for Closed Water Heating System (Honeywell)

This permits some water of volume 9 to pass into and up the circulating tube 4, carrying continually with it a small quantity of mercury. When

this stream of water and mercury reaches the top of tube 4, the two substances separate; the water continues to rise, passes up and around deflector 2 and out opening 1 to the expansion tank; the mercury passes over the edge of tube 4 when it reaches the enlarged chamber 3 at top and falls through space 8 in the stand-pipe to inner mercury chamber 15 where it causes a raising of the mercury level in reservoir 13. This, in turn, governs the opening at inlet 14, thus acting similar to a balanced valve and controls the flow of water through circulating tube 4.

Under all normal working conditions, the positive circulation of mercury upward through tube 4 and downward through pipe 5 assures retaining the mercury within the circulating tubes of the apparatus, and establishes and maintains the desired pressure on the system (carried at 10 lbs. per square inch), while all water, in excess of that needed to produce an expansion force of 10 lbs. per square inch, is permitted to pass to the expansion tank.

As the water throughout the system cools, the action of the mercury and water in the apparatus is exactly reversed from the above explanation.

As contraction occurs, the force of expansion gradually reduces so that the pressure acting on the surface of mercury in the lower chamber is reduced and a condition of unbalanced pressure occurs at openings 1 and 6, with the slightly greater pressure existing at opening 1. This pressure lowers the water and mercury level in tube 4 and pipe 5 until water may pass through openings 14 and 15, thence upward through the mercury 13, and mix with water volume 9 from where it may again flow into the heating system. The manufacturer of this apparatus states that "a pressure of ½ lb. at opening 1, causes water to flow from the expansion tank into the system."

Work Problem H-6-4

APPLICATION OF THE MERCURY SEAL TO WATER HEATING SYSTEMS

This means of accelerating the flow of heated water may be applied with the expansion tank in either the attic or basement. Fig. H-6-2 shows a typical layout with air-tight expansion tank for use when the tank is located in the attic and operates as a down-flow system. It should be noted that all radiator connections are made at the bottom. Fig. H-6-3 shows a typical layout with an open tank for a down-feed tank in attic system.

Work Problems H-6-5 and H-6-6

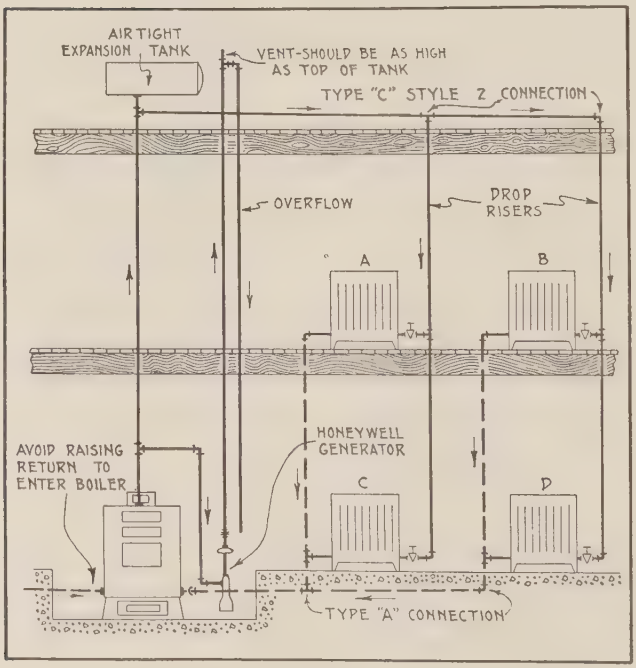


Fig. H-6-2. Typical Accelerated Down-feed Water Heating System with Air-Tight Tank in Attic. (Employing a Honeywell Generator)

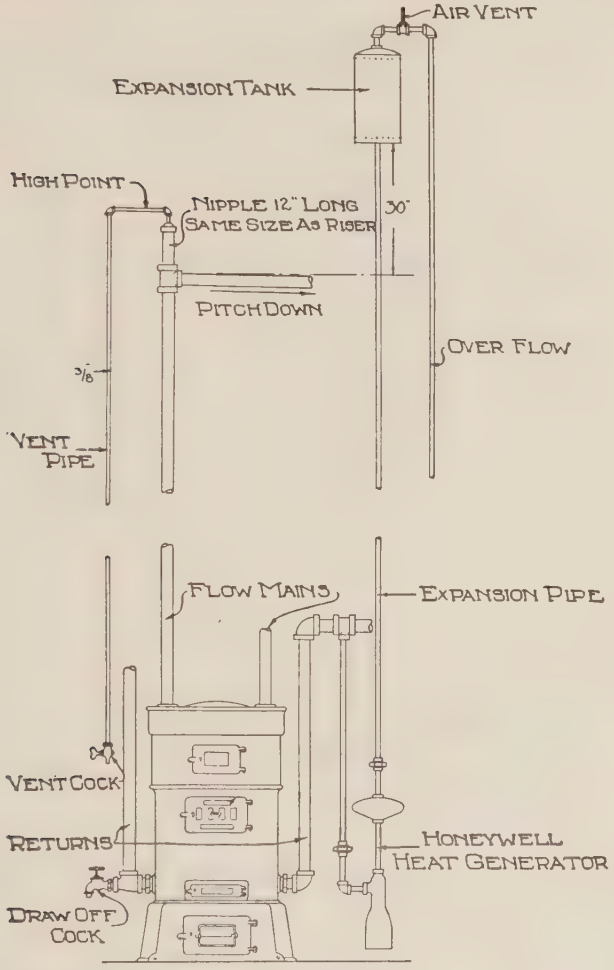


Fig. H-6-3. Typical Accelerated Down-feed Water Heating System with Open Tank in Attic. (Employing a Honeywell Generator)

PIPING DETAILS

The design of the piping should be carried out for any accelerated system with as much care as was stressed as being necessary for an open-tank system. Smaller valve sizes for equal radiation being permitted. Table H-6-3 is presented to be used for systems employing the mercury seal system described.

TABLE H-6-3
SIZES OF VALVES RECOMMENDED FOR A CLOSED WATER HEATING SYSTEM EMPLOYING A HONEYWELL GENERATOR

RADIATOR LOCATION	DIRECT RADIATION SQUARE FEET	VALVE SIZE
FIRST FLOOR	UP TO 30	½"
	FROM 30 TO 60	¾"
	FROM 60 TO 100	1"
SECOND FLOOR	UP TO 40	½"
	FROM 40 TO 100	¾"
	OVER 100	1"
THIRD FLOOR	UP TO 50	½"
	FROM 50 TO 125	¾"
	OVER 125	1"
THE VALVE ON THE RADIATOR AT THE END OF THE MAIN SHOULD, GENERALLY, BE MADE ONE SIZE LARGER THAN THE TABLE INDICATES.		

Risers should be made the same size as the radiator valve they supply except in the case of a ½-in. valve. No riser smaller than ¾ in. is recommended. Where a ½-in. valve is used on a second or higher-floor radiator, a ¾-in. riser should supply it. Also, when two radiators on a second or higher floor are supplied through ½-in. valves, a ¾-in. riser is considered ample. In general, the area of all risers should equal or exceed the total area of valves supplied. If one continuous riser is to supply a ¾-in. valve on a second-floor radiator and a ½-in. on a third-floor radiator, the riser should be 1 in. from the main to the second floor and ¾ in. from second to third floor.

A 1-in. riser to a second or higher floor should never be taken from a 1¼-in. main; nor a 1¼-in. riser from a 1½-in. main; nor a 1½-in. riser from a 2-in. main. The main should never be less than two pipes larger.

Long branches from mains to heels should be avoided and long runs between upper ceilings and floors should not be permitted. Additional and smaller risers should be used.

Work Problem H-6-7

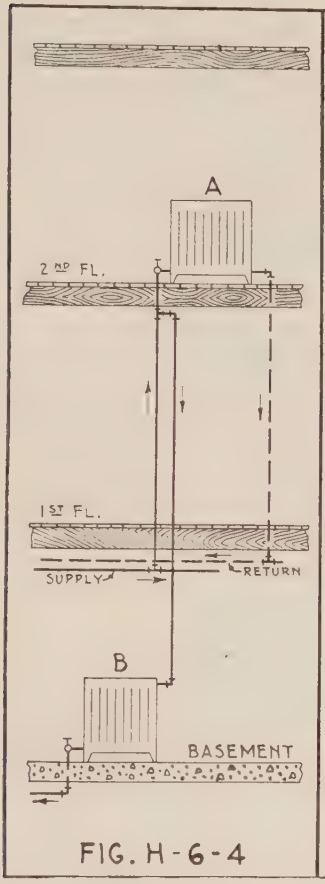


Fig. H-6-4. Drop Piping for Supplying Basement Radiator.

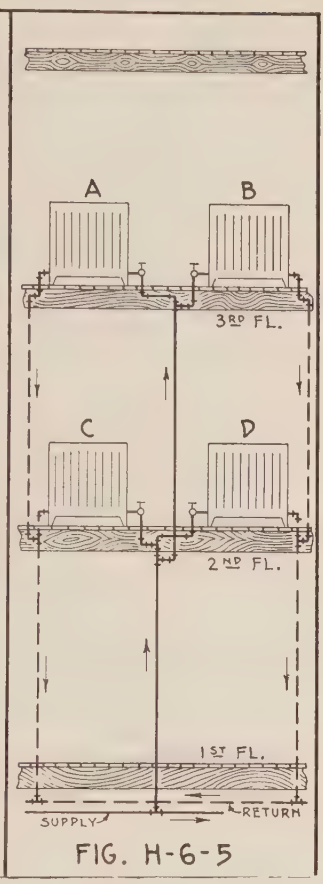


Fig. H-6-5. Riser and Radiator Connections for Second and Third Floor Radiators. (Used with Problem H-6-7)

TABLE H-6-4
EXPANSION TANK CAPACITIES
FOR USE WITH HONEYWELL GENERATOR

RADIATION SQ. FT.	CAPACITY REQUIRED GALLONS
600 OR LESS	21
600 - 1000	30
1000 - 1400	40
1400 - 2000	60
NOTE:- TWO OR MORE SMALLER TANKS MAY BE SUBSTITUTED FOR ONE LARGER TANK.	

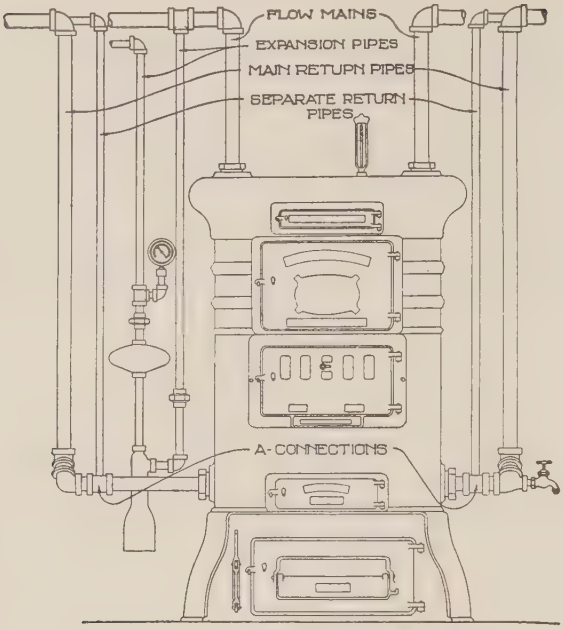


Fig. H-6-6. Method of Connecting Separate Returns into Main Return at Boiler

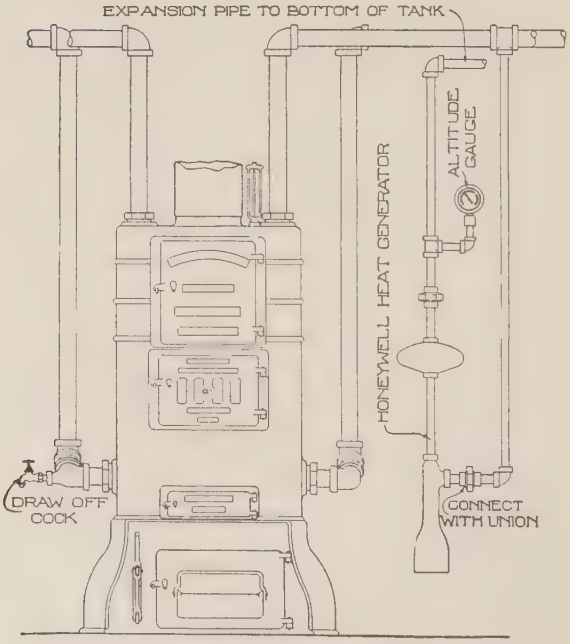


Fig. H-6-7. Method of Connecting the Generator to Mains at the Boiler

Mains and branches should be proportioned by valve areas, as explained in a previous lesson. In general, they should be pitched ½ in. in 10 ft. No

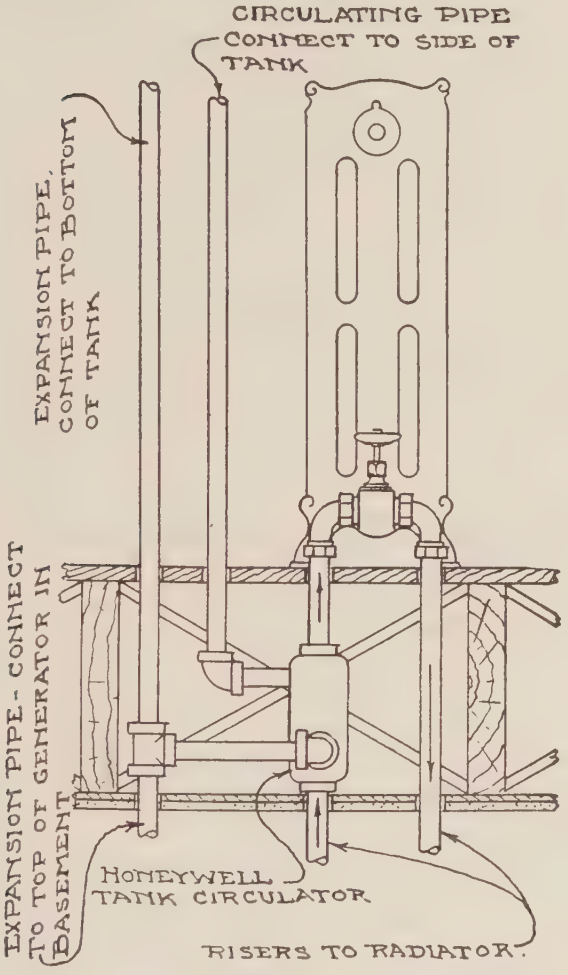

CIRCULATING PIPE
CONNECT TO SIDE OF TANK
EXPANSION PIPE, CONNECT TO BOTTOM OF TANK
EXPANSION PIPE - CONNECT TO TOP OF GENERATOR IN BASEMENT
HONEYWELL TANK CIRCULATOR
RISERS TO RADIATOR

Fig. H-6-8. A Tank Circulator (Honeywell) as a Protection Against a Freezing Expansion Line

main smaller than 1¼ in. should be used. It is considered good practice to reduce mains up to 2½ in., inclusive, no more than one pipe size after leaving the boiler. More than one reduction may be made without danger of sluggishness where the main is 3 in. or larger. When a 1½-in. main leaves

the boiler and reduces to 1¼ in., this size should be carried to the heel of the connection leading to the last radiator on the main. However, it is preferable to carry a main of this size to the end in order to avoid using a style B connection (Fig. H-2-2) and separate returns to the boiler, as shown in Fig. H-6-6.

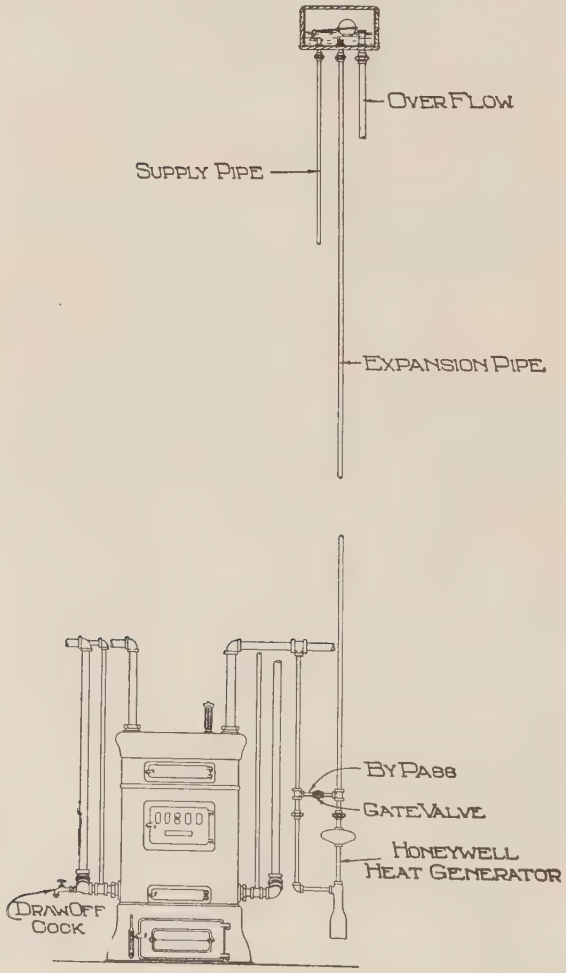


Fig. H-6-9. Application of an Automatic Expansion Tank to a Honeywell Generator Installation

The use of separate returns for radiators located near the boiler in a straight run up-feed water heating system, whether it be an open or closed-type system, is a most important consideration. Connections to the return header should be made as indicated in Fig. H-6-6 or, if the pipe is small, an extra hole may be drilled and tapped through the boiler shell. If connected into the return header, the necessary tee should be installed in the horizontal and not the vertical line, with side outlet in a horizontal position.

Work Problem H-6-8

A suitable manner of connecting up a basement wall or floor radiator is shown in Fig. H-6-4, the drop pipe being taken from the nearest flow riser. A separate return to boiler should be installed and the supply riser from main designed large enough to supply all radiation.

Work Problem H-6-9

Due attention should be paid to the manner of connecting branches to the mains, as was thoroughly covered in the second lesson devoted to water heating systems. See Fig. H-2-2 and H-2-4 and accompanying description.

MERCURY GENERATOR CONNECTIONS

The mercury generator should be located preferably in the basement near the boiler with the side opening connected to a tee in any flow or return pipe, as indicated in Fig. H-6-7. While the generator is usually placed as shown, it will function equally well if located on first, second or a higher floor, provided it is installed so that there are at least 30 in. between the top of the generator and the bottom of the expansion tank. Unions as shown should always be used for connecting the generator to the system in order that it may be disconnected easily for draining all water from the system.

ALTITUDE GAGE

The location of the altitude gage, shown in Fig. H-6-7, is preferable since by placing it in the ex-

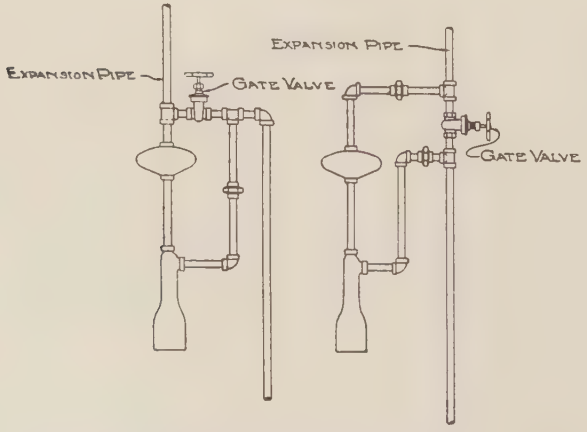
pansion pipe and above the generator, the pressure produced in the generator will not be indicated on the gage and the exact height of water in the system will be registered.

Work Problem H-6-10

EXPANSION TANK AND LINES

The expansion tank should be installed and connected as explained in a previous lesson, so far as piping is concerned, and with an open tank, the size will be the same as for an open system. (See Table H-5-3.) When possible, the expansion line should always be run so as to protect it against freezing. Where this possibility cannot be entirely eliminated, a tank circulator may be used, as illustrated in Fig. H-6-8. Expansion tanks provided with a float valve for automatically introducing water into the system have certain advantages over the cylinder type as they may be installed where there is no danger of freezing and present a better appearance. Fig. H-6-9 shows method of connecting such a tank. If, however, an automatic tank is used, a by-pass should be provided for the generator as shown in Fig. H-6-9 and cut below.

Work Problem H-6-11

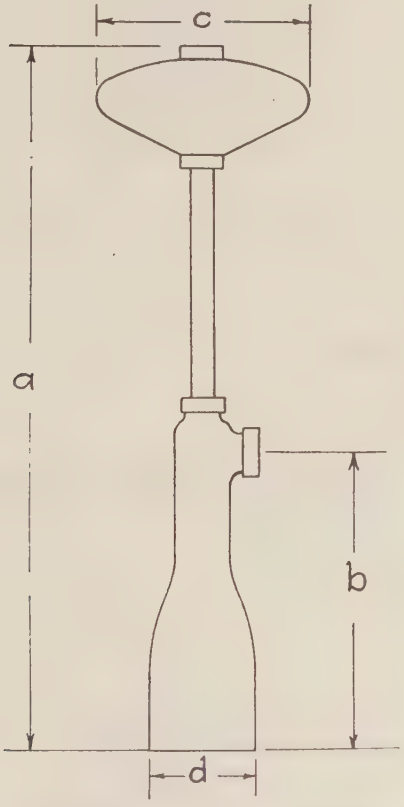


Two Methods of Connecting Generator with By-Pass.

APPLICATION OF A CLOSED SYSTEM TO HEATING LONG LOW BUILDING

Fig. H-6-10 shows a three-wing structure for which a down-feed closed water heating system is to be designed. The radiation being stated in the problem the student is to proportion all piping and submit on sheet provided.

Work Problem H-6-12



Generator	a	b	c	d
No–1	28½"	12½"	8½"	4½"
No–2	29¼"	12½"	9"	5"
No–3	30½"	12"	12½"	6"
No–4	30½"	12"	12½"	7"

Roughing-in Measurements for Different Size Generators.

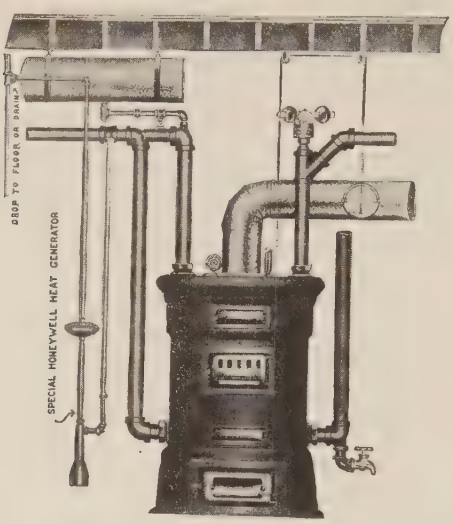


Fig. H-6-11. Application of Special Honeywell Heat Generator to a Tank-in-Basement System.

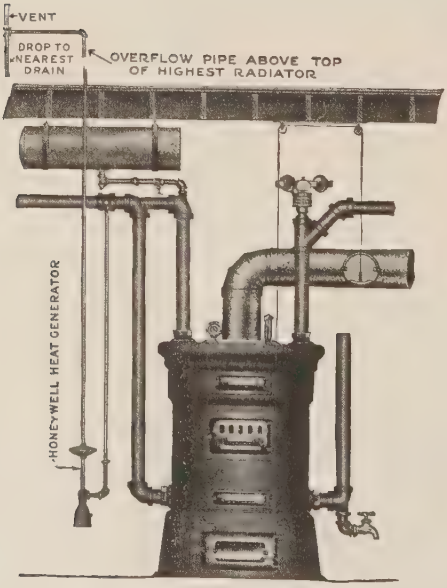


Fig. H-6-12. Application of Regular Honeywell Heat Generator to a Tank-in-Basement System.

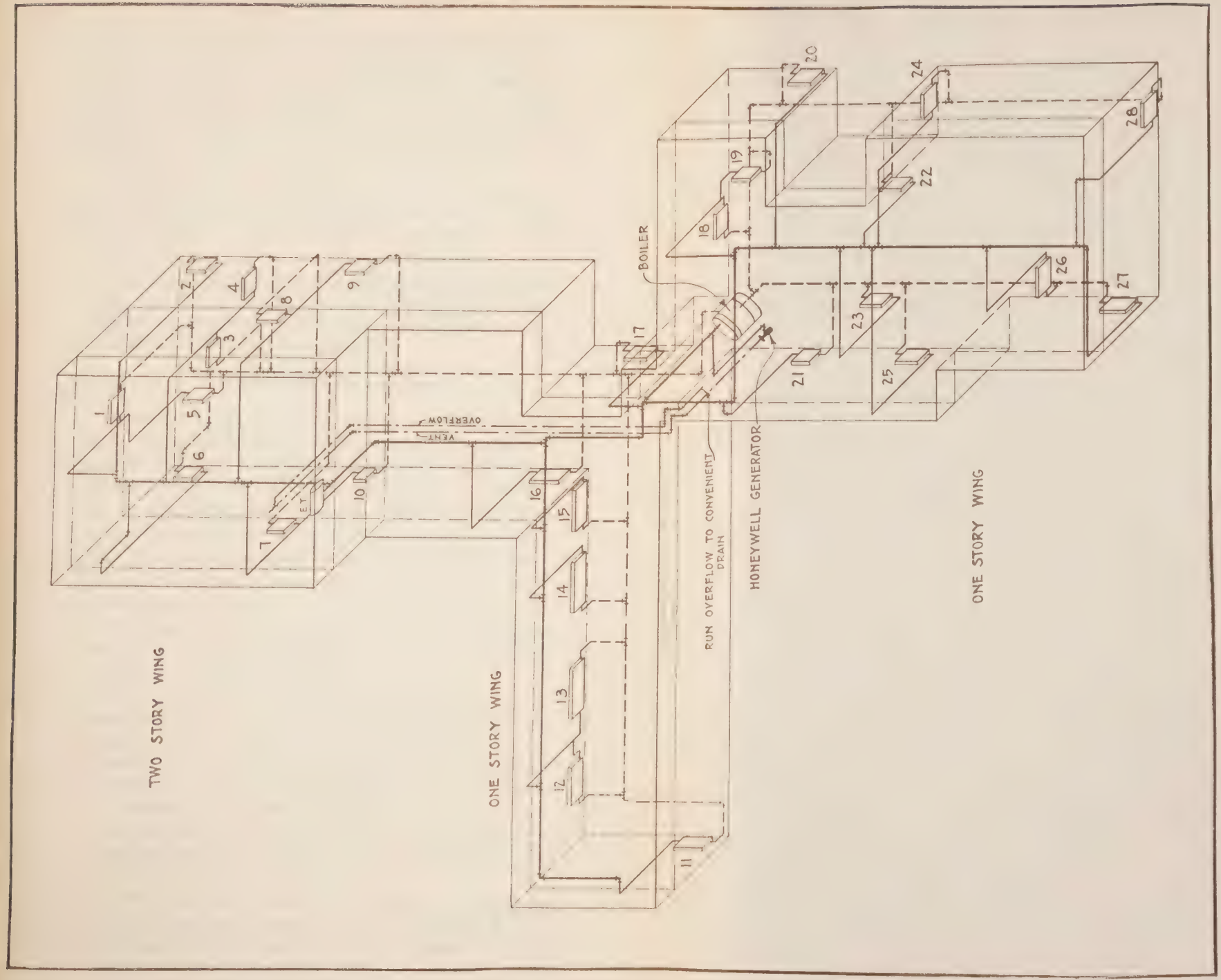


Fig. H-6-10. Application of a Honeywell Heat Generator to a Down-feed Water Heating System Designed for a Long Low Building
(Used With Problem H-6-12)

The mercury-seal generator may also be used with a tank-in-basement system where it may be preferable or necessary to locate the expansion tank in the basement, instead of above the radiation. A special mercury-seal generator is used. Figures H-6-11 and H-6-12 show the method of piping.

When a tank-in-basement system is designed, an air-tight expansion tank must be used. Table H-6-4 shows tank capacities for various size systems.

Regulation in a tank-in-basement system of this type may be accomplished by means of a Syphon water regulator whereby the heater drafts are controlled by the water temperature.

Another type of closed water heating system, here illustrated, affords an example in which a special differential relief valve is used and an automatic damper regulator controls the fire to produce the desired room temperature. Fig. H-6-13 shows a typical layout for a down-feed closed system of this type, with tank in attic. Fig. H-6-14 shows the special apparatus applied to an up-feed tank-in-basement system.

The essential parts of this system are the damper regulator, the differential-pressure relief valve and the air-tight expansion tank.

The automatic temperature-damper control is governed by the change in temperature of the water in the system—not by pressure. The active element is a multiple-disc thermostat the movement of which, through lever action, opens and closes the dampers of the heater. See Fig. 8-6-15.

The differential-pressure relief valve is shown in section in Fig. H-6-16. The manufacturer describes its operation as follows:

> "The water enters the differential-pressure relief valve at A, passes through opening B into by-pass C, to opening D into top chamber E. The valve member is closed tight when not under pressure by means of the tension of coil spring 7.

"As pressure accumulates from the system, diaphragm 9 is forced against adjustable plate 8, which pushes down upon valve stem 4. When pressure has become sufficient to counteract the tension of coil spring 7, the valve unseats and allows the water from chamber A to pass out through middle chamber at opening G. As the pressure recedes, the coil spring pulls valve disc back against its seat when overflow ceases."

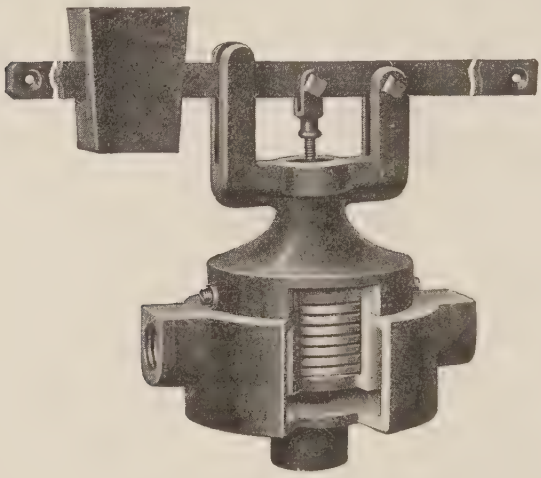
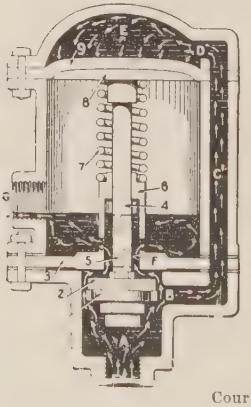


Fig. H-6-15. Automatic Temperature Damper Control.



Courtesy H. A. Thrush Co.

Fig. H-6-16. Differential Pressure Relief Valve Used with the Thrush System

The tanks used with this system must be air tight. The manufacturer specifies four sizes with dimensions and capacities as given in Table H-6-5. The specified size should be used. If a system consists of more than 2000 sq. ft. of radiation, more than one tank should be installed and connected as shown in Fig. H-6-17.

Work Problem H-6-13

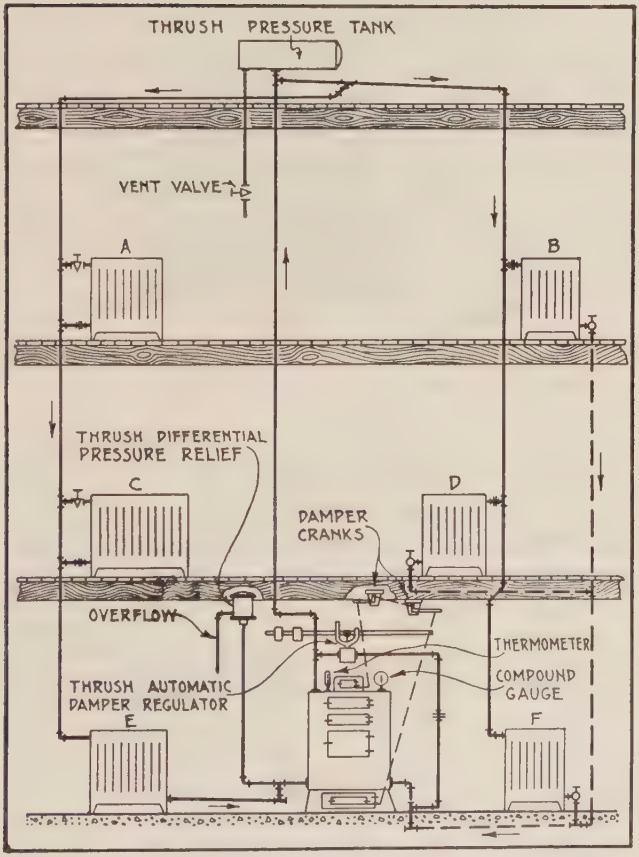
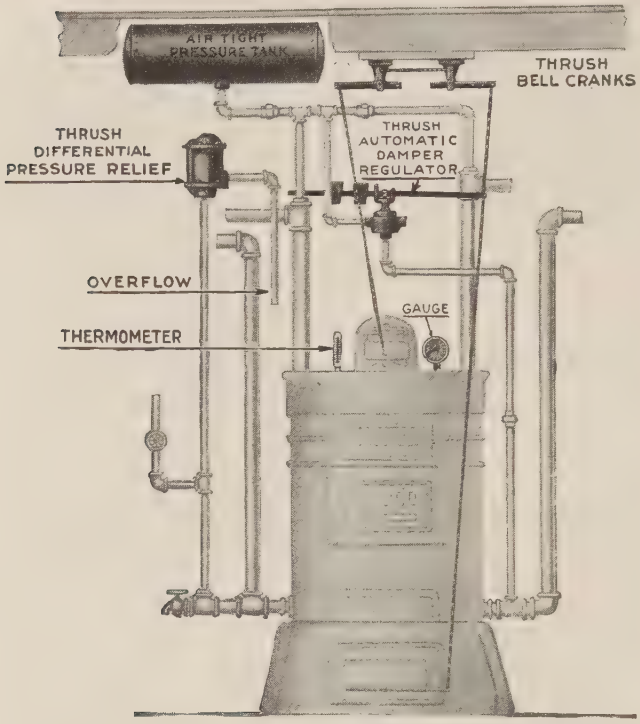


Fig. H-6-13. Typical Design for a Thrush Down-feed Forced Water Heating System with Tank in Attic



Courtesy H. A. Thrush Co.

Fig. H-6-14. Application of the Thrush System to an Up-feed Tank-in-Basement Forced Water Heating System

TABLE H-6-5
EXPANSION TANK CAPACITIES FOR THRUSH FORCED WATER HEATING SYSTEM

SIZE NO.	DIMENSIONS INCHES	CAPACITY SQ. FT. RADIATION
0	10 × 48	350
1	12 × 48	750
2	12 × 60	1250
3	14 × 60	2000

In Fig. H-6-18 the temperature control damper regulator system is shown installed on a sectional cast-iron boiler.

Work Problem H-6-14

When a low-ceiling basement is encountered where it is impossible to place the pressure tank to permit making the piping connections as shown in preceding figures, the manufacturer recommends the arrangement shown in Fig. H-6-19. The pressure-tank connection is taken off at the top of the two flow risers, thus trapping the air. The end of the pipe is then dropped low enough for connecting into the bottom of the pressure tank.

Work Problem H-6-15

PIPING SYSTEM DESIGN

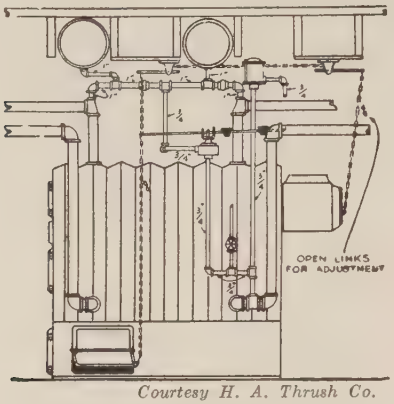
The manufacturer of this system specifies slightly different valve sizes for radiators (see Table H-6-6) than were given in a similar table recommended by another manufacturer. While the use of either table should give equally good results, the student should follow the recommendations of the respective manufacturer whose apparatus he intends to use. In laying out and proportioning a system, all preceding instructions as to sizes for mains, branches and risers and the manner in which they are connected up should be observed.

Work Problem H-6-16

TABLE H-6-6
SIZES OF VALVES RECOMMENDED FOR A CLOSED WATER HEATING SYSTEM OF THE THRUSH DESIGN

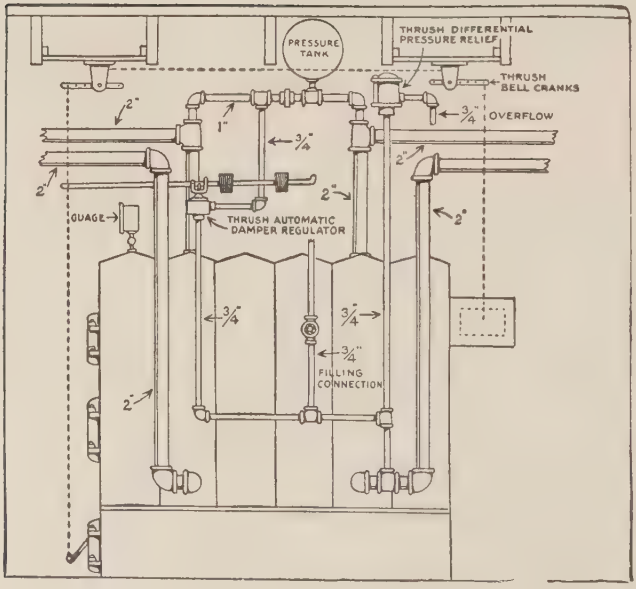
RADIATOR LOCATION	DIRECT RADIATION SQUARE FEET	VALVE SIZE
FIRST FLOOR	UP TO 70	3/4"
	UP TO 125	1"
	OVER 125	1 1/4"
SECOND FLOOR	UP TO 25	1/2"
	UP TO 90	3/4"
	OVER 90	1"
THIRD FLOOR	UP TO 40	1/2"
	UP TO 120	3/4"
	OVER 120	1"

THE VALVE ON THE RADIATOR AT THE END OF THE MAIN SHOULD, GENERALLY, BE MADE ONE SIZE LARGER THAN THE TABLE INDICATES.



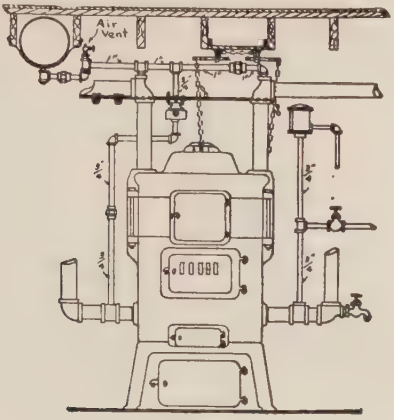
Courtesy H. A. Thrush Co.

Fig. H-6-17. Illustrating the Use of Multiple Tanks for Systems in Excess of 2000 Sq. Ft. Direct Radiation.



Courtesy H. A. Thrush Co.

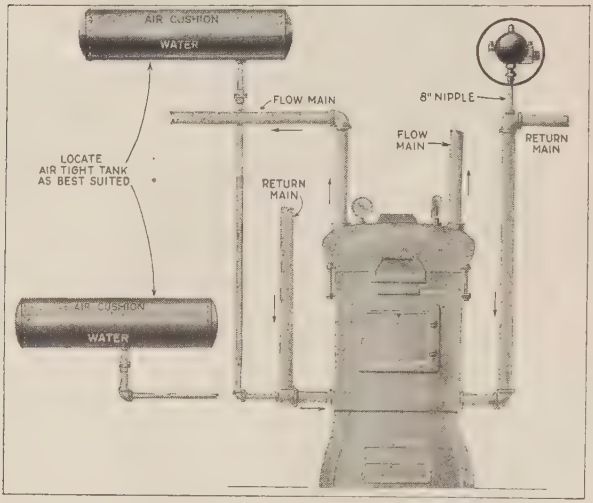
Fig. H-6-18. Thermostatic Damper Control Applied to a Sectional Cast-iron Boiler



Courtesy H. A. Thrush Co

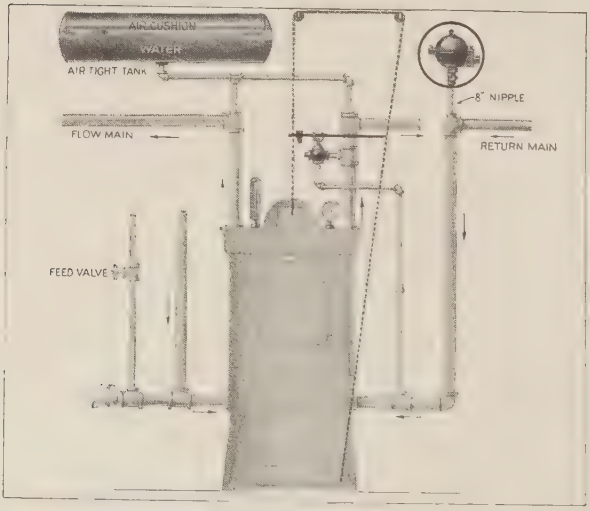
Fig. H-6-19. Application of Thermostatic Damper Control System to a Low Ceiling Basement

Another application of the relief valve and air-cushion principle is illustrated in Fig. H-6-20 and H-6-21. The relief valve is of the gravity-action type (see Fig. H-6-22). It is set to relieve pressure on the system at 30 lbs. per square inch. The lead ball is held in vertical alignment by means of a piston of suitable material which moves in a guide at top and at bottom. With a closed system using this valve, an air-tight pressure tank is required. The system is operated by first driving all air from the radiators and piping by filling them with water, relieving the first-floor and then higher-floor radiators in turn so that the system is under none but hydrostatic pressure. The air entrapped in the pressure tank acts as an air cushion when the water in the system expands due to heating. As long as the system is operated within temperature limits that do not require the relief valve to discharge water from the system, no make-up should be required. The altitude gage pointers are used as the index to determine when additional water should be admitted to the system.



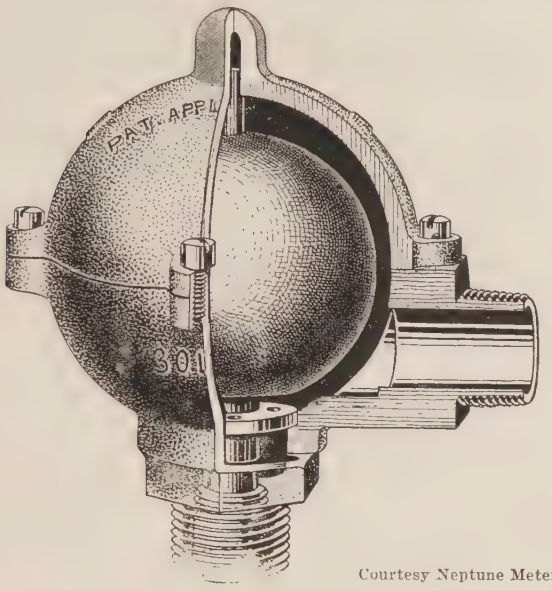
Courtesy Neptune Meter Co.

Fig. H-6-20. Application of Red-Top Relief Valve to an Air-Tight Tank-in-Basement Water Heating System



Courtesy Neptune Meter Co.

Fig. H-6-21. Application of Red-Top Relief Valve with Thermostatic Control



Courtesy Neptune Meter Co.

Fig. H-6-22. Gravity Action Type Ball Relief Valve for Closed Water Heating System

CLOSED WATER HEATING SYSTEM WITHOUT TANK

The essential parts of the closed water heating system in which the tank is omitted are a specially-designed relief valve and a water-reducing valve, combined with a damper regulator. It thereby embodies automatic damper regulation, automatic relief and automatic supply.

The relative position of the various parts of this type of system are shown in H-6-23. The reducing valve is set to close at a pressure of 10 lbs. per square inch, which is usually ample to fill the radiators. As the water in the system is heated and expands, the pressure rises proportionally until a value of 25 lbs. is reached when the relief valve operates and permits a small quantity of water to pass out through the discharge to floor drain.

The damper regulator is set to maintain a desired water temperature. If the relief valve opens before that temperature is reached, it is permitted to continue to discharge until the temperature of the water has risen to the proper point, when the

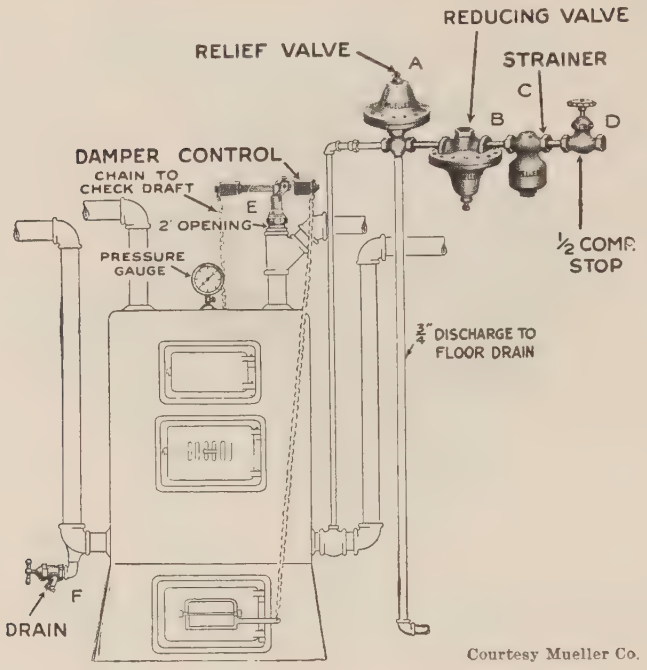


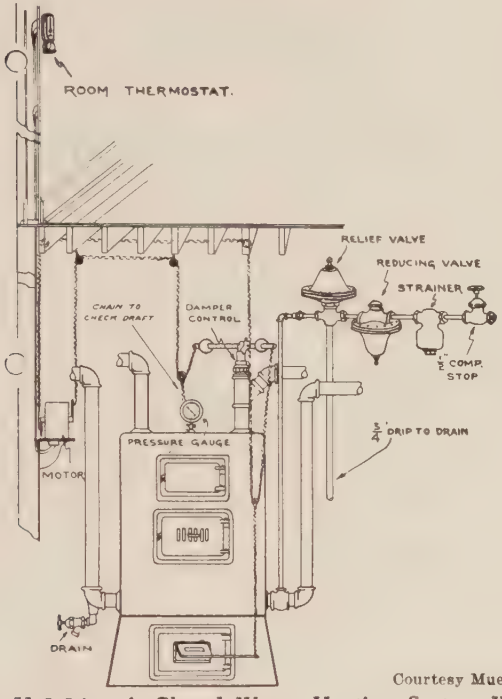
Fig. H-6-23. Closed Water Heating System Without Expansion Tank

damper regulator functions to check the temperature rise. The relief valve then closes. The temperature of the water drops and the pressure follows suit. This drop in pressure continues until it reaches 10 lbs. per square inch when the reducing valve opens and admits enough water to replace that passed by the relief valve. It is essential that air be released regularly from the radiators in order that it may not accumulate to a degree sufficient to interfere with proper heating of the system. It is unnecessary, however, to fill the system manually.

The manufacturer of this equipment recommends that the damper regulator be installed as shown in Fig. H-6-23 unless its position at the boiler is too high to operate the weights for different desired temperatures conveniently. An alternate method is to insert a tee in the vertical section of the flow main and install the regulator in another tee placed in the same horizontal place, with a bottom connec-

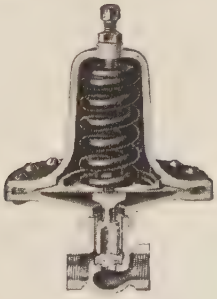
tion carried to the return header. When a room thermostat is used the connections should be as shown in Fig. H-6-24.

Work Problem H-6-17



Courtesy Mueller Co.

Fig. H-6-24. A Closed Water Heating System With Tank Omitted and Thermostatic Control



Mueller
Relief Valve

PIPING DESIGN

Either of the tables given above may be used for determining the size of radiator valves while risers, branches, and mains should be proportioned by the valve-area method as previously described.

Work Problem H-6-18

PART H.

HOT WATER HEATING

LESSON 7.

Designs and Inspection Reports

GRAVITY

WATER HEATING SYSTEMS.

DESIGNS AND INSPECTION REPORTS.

This lesson is devoted largely to the preparation of designs, a study of selected existing systems that require remodeling and the preparation of inspection reports thereon. Practically no new work is taken up in this lesson, but rather an application of principles that have been explained in preceding lessons and with which the student should be so familiar that he should have no difficulty in comprehensively understanding and successfully solving the assignments.

Thus the work of this lesson will enable each student to demonstrate to himself conclusively his grasp of the subject to date.

Fig. H-7-1 shows a basement piping layout for a two-pipe up-feed water heating system installed in a three-story residence.

A competent heating engineer was called in to advise the contractor who installed this system as to why it did not function uniformly and how it should be altered so that the residence would be properly heated.

The plant was fired and a test was run by the engineer to determine how circulation was moving throughout the system. He taped and insulated exposed-bulb thermometers on different sections of the mains, branches and to the inlet and outlet pipes to the different radiators. Temperatures were observed while the plant was warming up and after it should have reached a condition to assure steady and even circulation.

It was observed that water was circulating rapidly to the following radiators:

Southwest bedroom on second floor.
West bathroom on second floor.
West bedroom on third floor.
Living room on first floor.

It was also noted that the water in the returns of the above radiators had a tendency to flow away from the boiler in the main return line and start reversed circulation in branches to other radiators nearest on the main. This condition, however, was only temporary, while the plant was warming up. It seemed to correct itself after the plant had been in operation for one to two hours and circulation at these points was fairly uniform.

Circulation to the following radiators was impaired. The average temperature of the water in them was slightly more than 10° lower than those listed above which were nearer the boiler.

Southeast bedroom on second floor.
Kitchen.
Entrance Hall.
Northeast bedroom on second floor.

There was practically no circulation to and from the following radiators:

East bathroom on second floor.

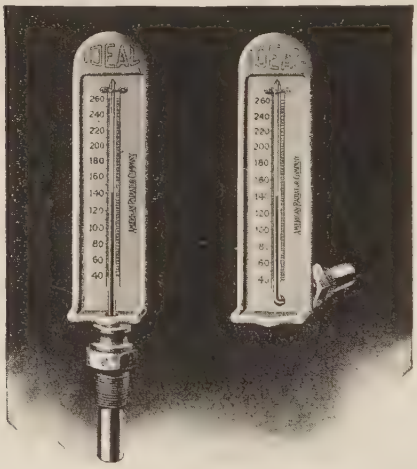
East bathroom on third floor.

Music room.

In the case of the radiator in the music room, while it was "cold," as compared to those near the boiler, yet it was observed that the return connection was warmer than the supply.

All risers to second and third-floor radiators are concealed in partitions, and branch connections to these radiators are made under the floors. In view of these conditions, changes above the basement should be avoided unless absolutely necessary.

Work Problem H-7-1



Straight and Angle Type Hot Water Thermometers Used in Hot Water Boilers.

CHECKING AND APPROVAL

The system shown as Fig. H-7-2 has been prepared for a two-story oblong residence. The sizes of the radiators are stated in Problem H-7-2. The student is to consider that he is assigned to check this design and approve or disapprove it as a straight-run two-pipe up-feed water heating system. If he disapproves it in whole or in part, he is

to accompany his disapproval by a report explaining why he has disapproved and what changes he would require before it would receive his approval.

Work Problem H-7-2

It should be noted that the chimney for the system shown in Fig. H-7-2 is located on the south side of the house and that the radiators on the north side are consequently the fartherest away from the boiler.

Work Problem H-7-3

Altitude Gage for indicating the height of the water in the system.

Combination Altitude Gage and Thermometer for indicating height of water in the system and temperature of water in the boiler on the same dial.

Courtesy American Radiator Company.

Fig. H-7-3 shows ten radiators located on two floors, with the boiler in the basement. The student will demonstrate his grasp of the principles covered in preceding lessons by designing six different systems to supply these radiators, observing all directions previously given as to special equipment,

piping, size of runs, connections and all points that contribute to correctly designed systems of water heating.

Work Problems H-7-4, H-7-5, H-7-6, H-7-7, H-7-8, and H-7-9

Fig. H-7-4 shows the basement plan of an old residence in which a water heating system is to be installed. There is a cellar under only a part of the dwelling. There is a space of about 2 ft. from the ground to the under side of the first-floor joists over that part marked "unexcavated." The location of radiators is shown and the area of each is given in the following problem.

Work Problem H-7-10

RISER DIAGRAMS

Riser diagrams may often be used to advantage in small, as well as large, work. They are prepared in conjunction with basement and floor plans showing the heating system.

After the size of radiators have been determined and their locations selected, each riser may be given a number as 1, 2, 3, etc., as noted in Fig. H-7-5, and a series of risers drawn on the same sheet, with the radiators that they supply noted by some designating letter or by the area of each. It is better to designate radiators by letter to avoid confusion when several may have the same area. The type of all connections may then be clearly shown, sizes of all pipes noted and the fitter given a blue-print that is easy and convenient to read and follow. In noting type of riser connections, the student should refer to Fig. H-2-4.

The basement plan and a typical floor-plan for a three-story duplex apartment house are shown as Fig. H-7-6 and H-7-7. The sizes of radiators have been determined as stated in the following problem and are located as shown by lettered oblongs in Fig. H-7-6.

The student is to design a complete water heating system, as specified in the problem, for this apartment, prepare a basement piping plan and a complete riser diagram.

Work Problem H-7-11

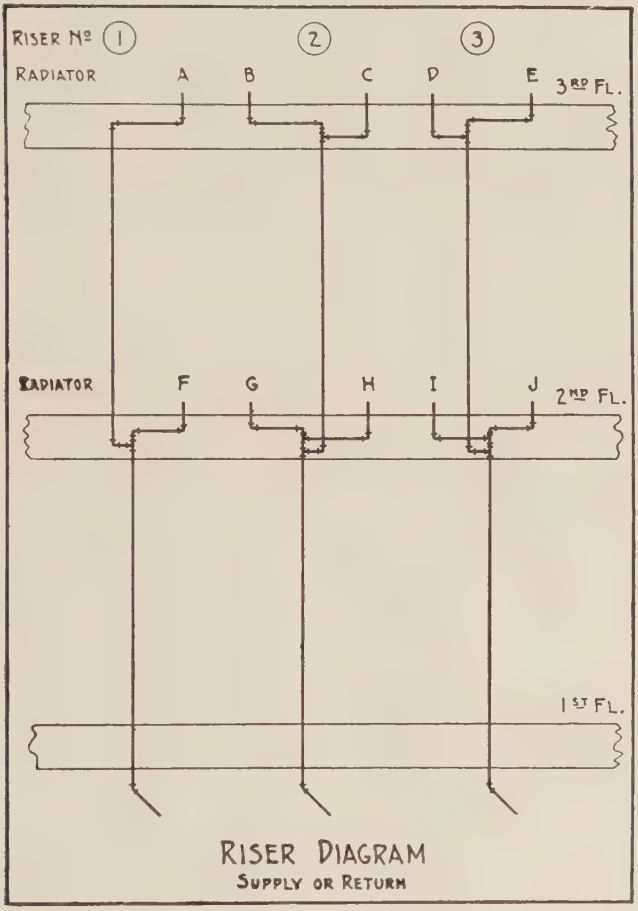


Fig. H-7-5. Typical Riser Diagram

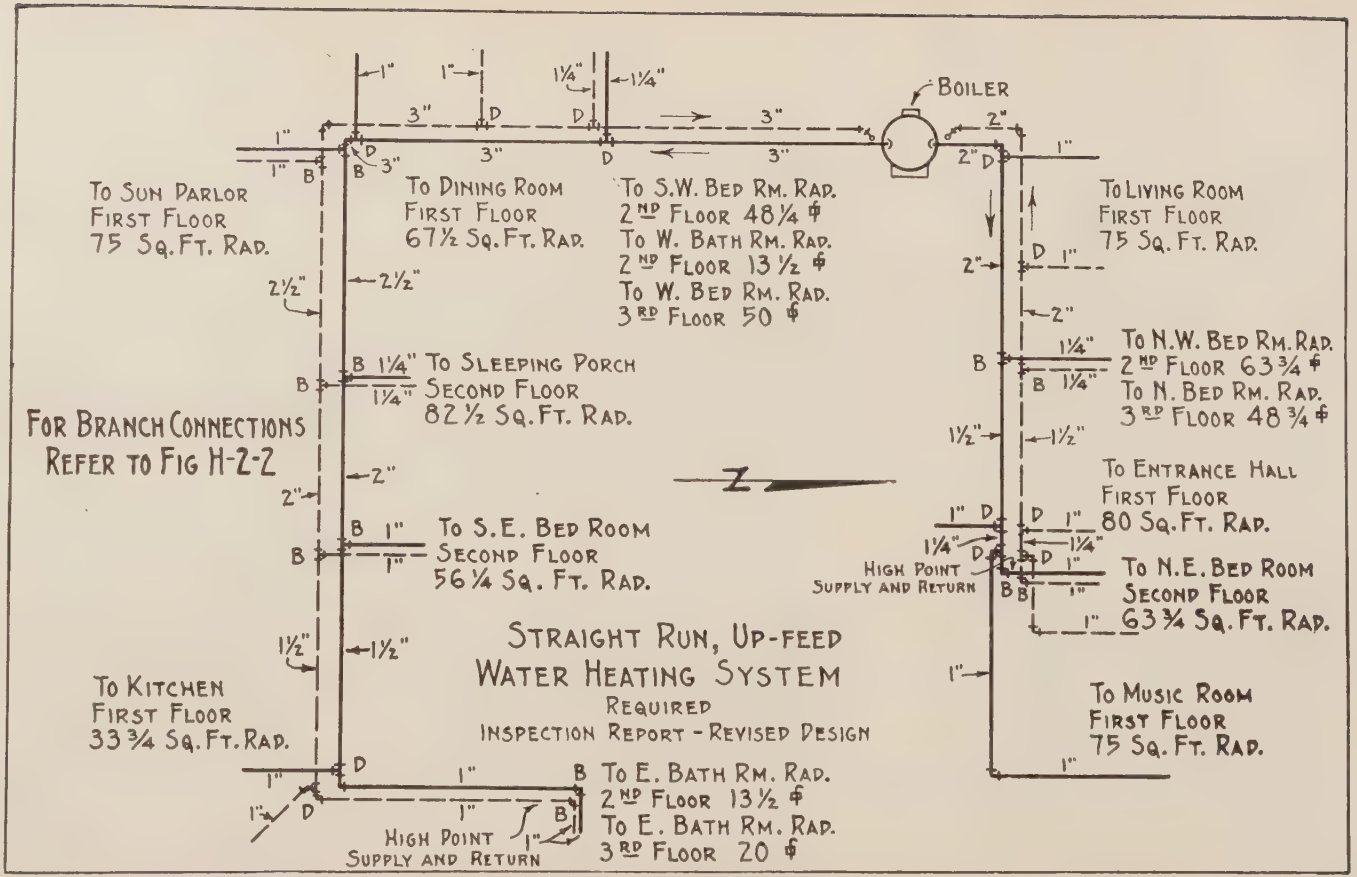


Fig. H-7-1. Basement Piping Plan on Which a Test Has Been Run and a Report Is to Be Prepared

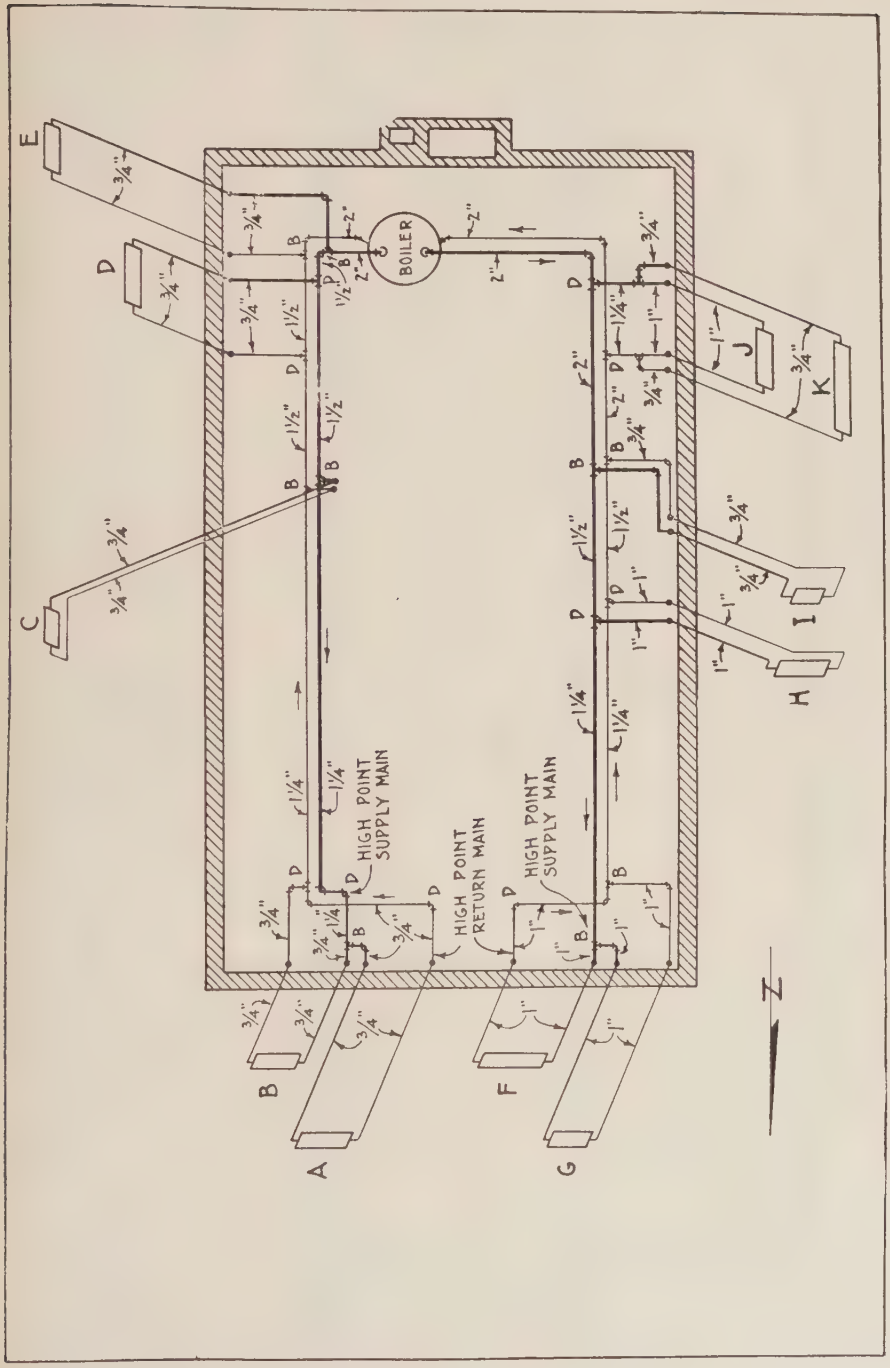


Fig. H-7-2. Basement Piping Plan Which Is to Be Checked, Approved or Disapproved

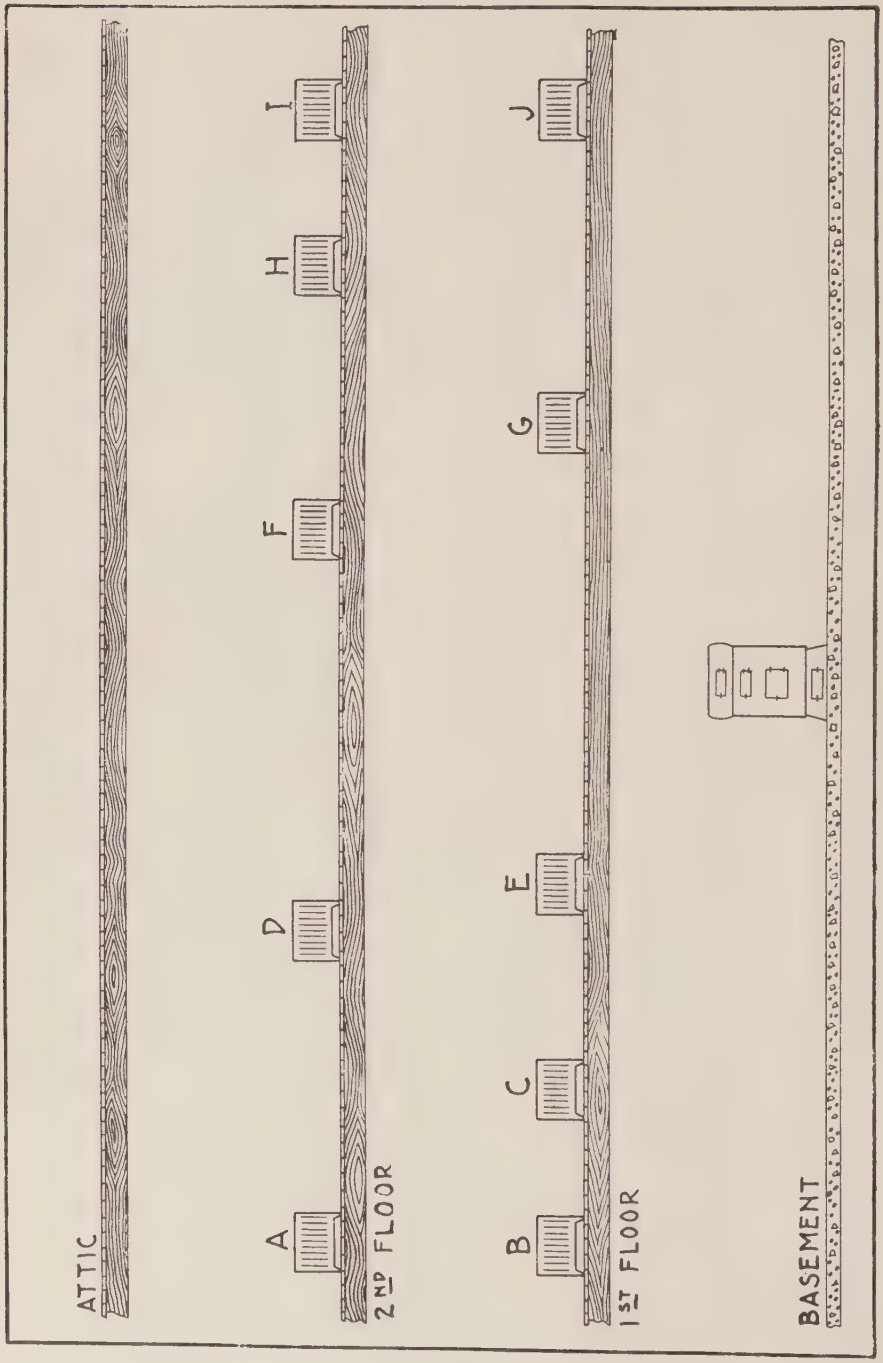


Fig. H-7-3. For use with Problem H-7-4 in designing a two-pipe up-feed straight run accelerated water heating-system with expansion tank in the attic, for radiation stated in Problem H-7-4.

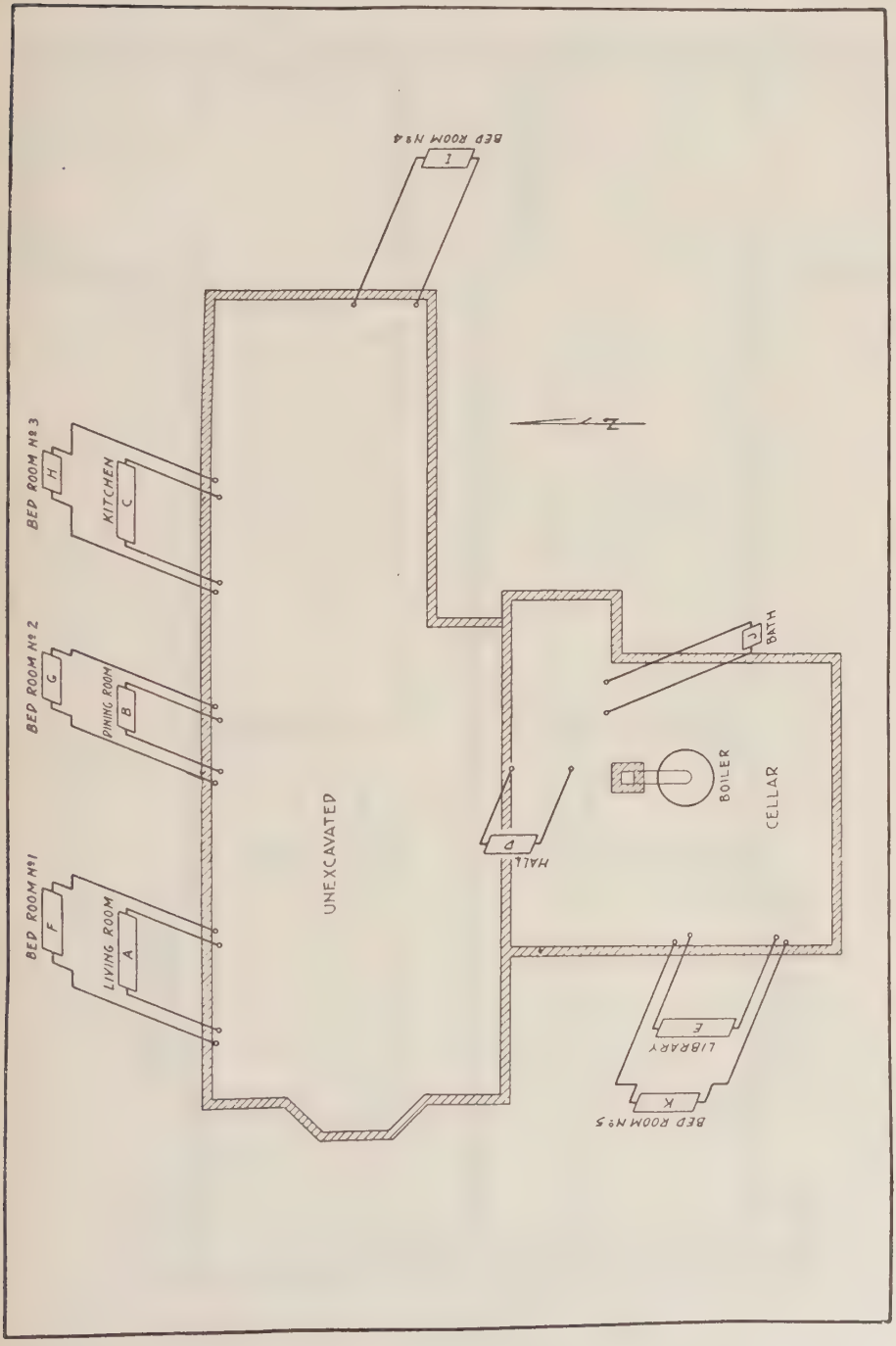


Fig. H-7-4. Radiators and Risers as shown are Installed. Mains are to be Designed and a Fitters Layout Prepared.

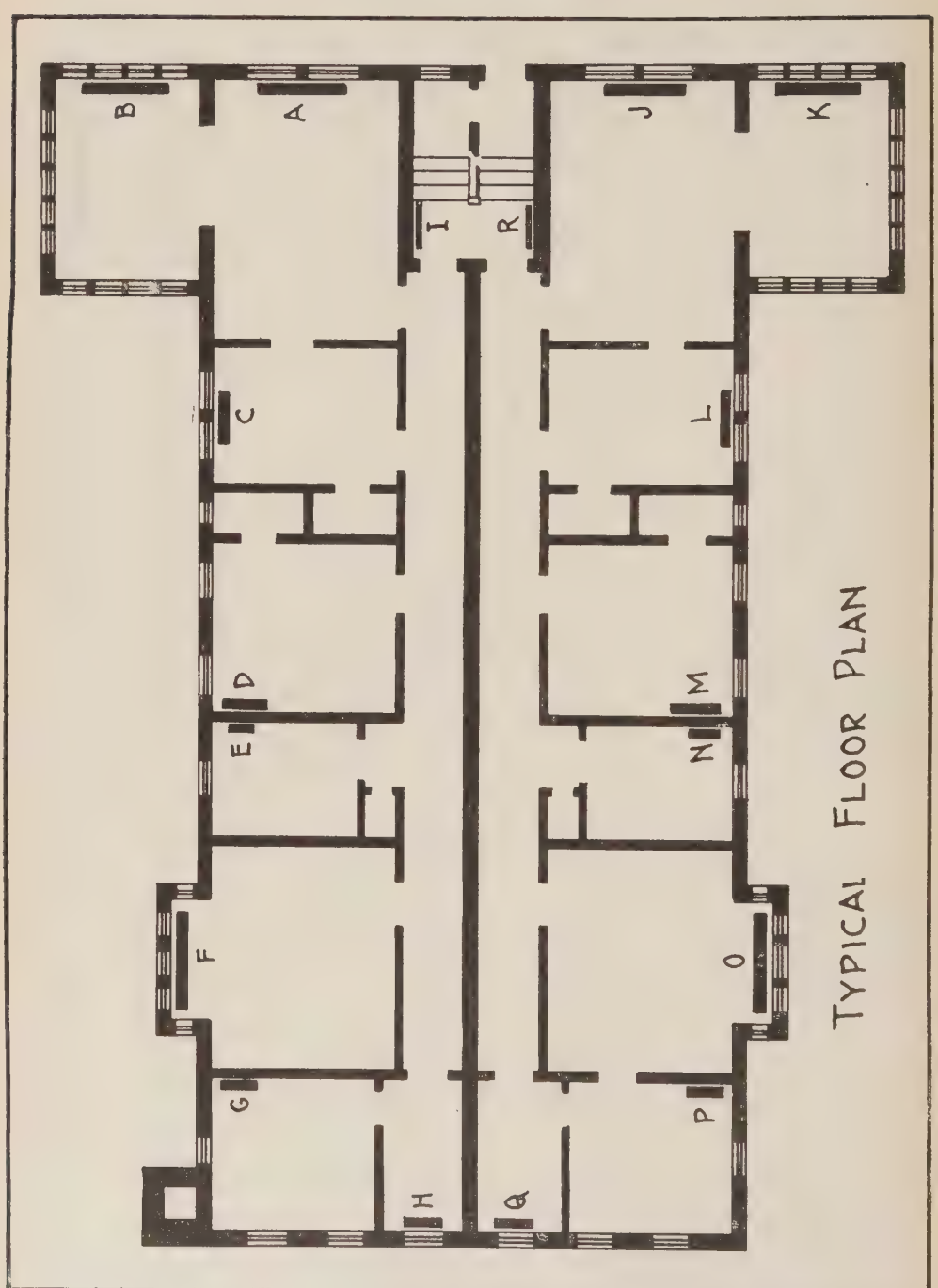


Fig. H-7-6. Typical Floor Plan of a Three-Story Duplex Apartment House with Radiators Located.

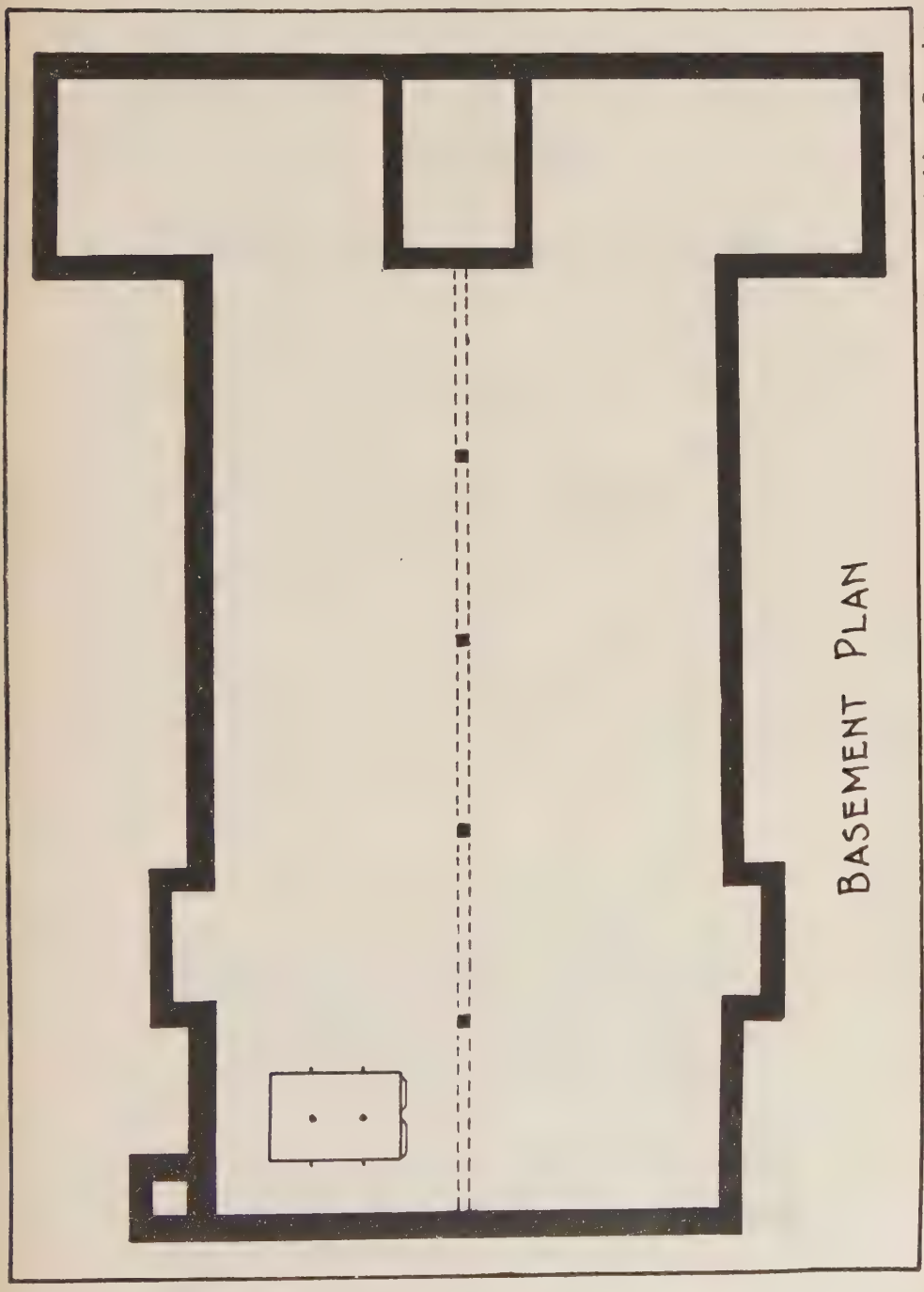


Fig. H-7-7. Basement Plan of Fig. H-7-6 on which a Complete Design is to be Submitted. Accompanied by a Complete Riser Diagram.

PART R.

RADIATORS AND RADIATION

LESSON 1.

Radiator Classification

RADIATORS AND RADIATION.

In order that the air in an enclosed space may be maintained at a desired temperature, there must be a unit of time as pass, during the same time, to the outside where the temperature is lower. The student should review the second lesson of Part I, "Fundamentals of Heating" and thereby refresh his memory on the principles of the transfer of heat.

When a room or building is heated by means of radiators there are three distinct steps that occur during the process. They are (a) the heat contained in the steam, water or other heating media passes to the inner surface of the radiator through

contact of the media and surface, (b) the heat passes through the walls of the radiator by conduction (See the first lesson of Part 1, "Fundamentals of Heating") and (c) the heat is given off from the outer surface by radiation and convection in the case of direct radiation and practically entirely by convection, only, for indirect heating.

The size of the radiator required or, as it is more generally termed, the amount of radiation required is expressed in square feet of radiating surface. This surface is the area of the outer surface of the radiator with which the air of the room may come in contact. Every square foot of surface of a given type or form of radiator under definite conditions of installation will give off or emit heat units at a definite rate.

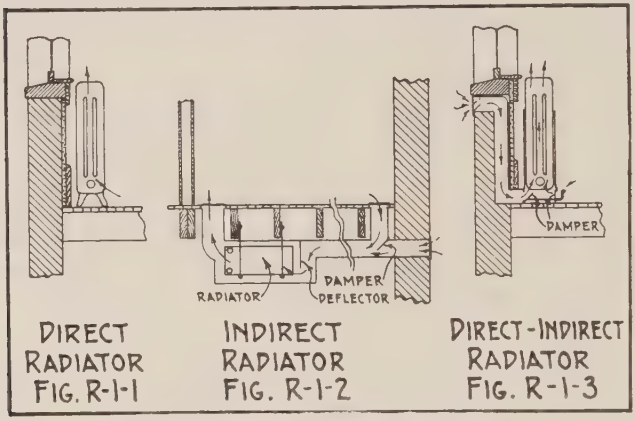
In preceding lessons of this course, in which it was necessary that the student know the amount of radiating surface used in the various water heating designs, it was always stated by assuming that the proper-size radiators had been previously determined. In this section, the student will be familiarized with the different types of available radiators, taught how to calculate required radiation, to locate it properly, and how different conditions of installation affect heat emission. Before considering these factors and their effect upon one another, it is essential that the radiators be classified.

CLASSIFICATION OF RADIATORS

Radiators may be classified under four separate and distinct headings (1) as to the manner in which the radiators are used to supply heat to the air in the space to be heated, (2) as to the material of which the radiator is built and its construction, (3) as to the form or type and (4) as to the medium used for heating the radiator.

Under the first designation, a radiator may be used to heat the air in a given space (a) by direct radiation, (b) by indirect radiation and (c) by

direct-indirect radiation. When the process is by direct radiation, the radiator is located within the space to be heated and is thereby surrounded only by the air within the space. An example of a direct radiator is shown in Fig. R-1-1.



Arrangements of Direct Radiators

When indirect radiation is used, the radiator is not located in the room to be heated but at some convenient place from which the heated air from the radiator is carried by convection or by fan or blower pressure through a duct to the room and is delivered through a floor or wall register. Fig. R-1-2 illustrates the manner in which indirect radiators are often installed in residential work. This class of radiation, therefore, may be arranged so as to recirculate inside air, introduce all outside air or proportions of each. Ventilation means are thereby possible with radiation so installed.

When direct-indirect radiation is employed for residential work, a ventilating radiator is used. Such radiators consist of a regular column direct radiator with a base-box fitted under and to it. The base-box contains two dampers, front and rear; the front damper opens into the room through which air in the room may enter, pass up through the radiator and be re-heated, while the rear damper, opening into a wall duct, permits outside air to enter, become heated as it passes up between the radiator sections for delivery into the room. The opening in the outside wall is fitted with louvres and screens to prevent entrance of dirt, insects and

water. A radiator of this form is shown in Fig. R-1-3. Thus air may be supplied for ventilating purposes when required or by closing the outside opening, the radiator may be operated as a direct radiator.

Work Problem R-1-1

Under the second designation (material and construction), there are four divisions, (a) cast-iron radiators, (b) pressed-steel radiatiors, (c) pipe-coil radiators and (d) tubular radiators. Cast-iron radiators, as their name implies, are cast with wall thicknesses of ¼ to 5/16 in. in different forms covered in detail under the third designation. Pressed-steel radiators consist of sheet-steel plates pressed and welded together by a double seam to form a column. The columns are riveted one to the other to form the radiator. Pipe-coil radiators consist of a series of 1-in. pipe (as the standard) united into a header or headers. Coils are sometimes built up of 1¼ or 2-in. pipe. Such radiators are used for direct radiation mainly in shops and factories. Their unsightliness makes them undesirable for other direct or direct-indirect work. While they have, in the past, been used for indirect and fan systems of heating, many engineers are now abandoning them in favor of units of the tubular type. Tubular radiators are built up of seamless copper tubing in different forms and so arranged as to provide a maximum of heating surface. They are fast becoming popular in connection with fan-blast and air-conditioning systems.

Work Problems R-1-2 and R-1-3

Under the third designation (form or type) there are many divisions possible, the principle of which are (a) floor radiators, or those with legs for standing on the floor, (b) wall radiators, or those built for attaching to the wall and (c) ventilating type radiators, or a radiator so built that air entering from below must pass to the top of the sections before it can leave the radiator.

Work Problem R-1-4

Floor-type radiators are available in many patterns, plain and artistic. Fig. R-1-4 illustrates one,

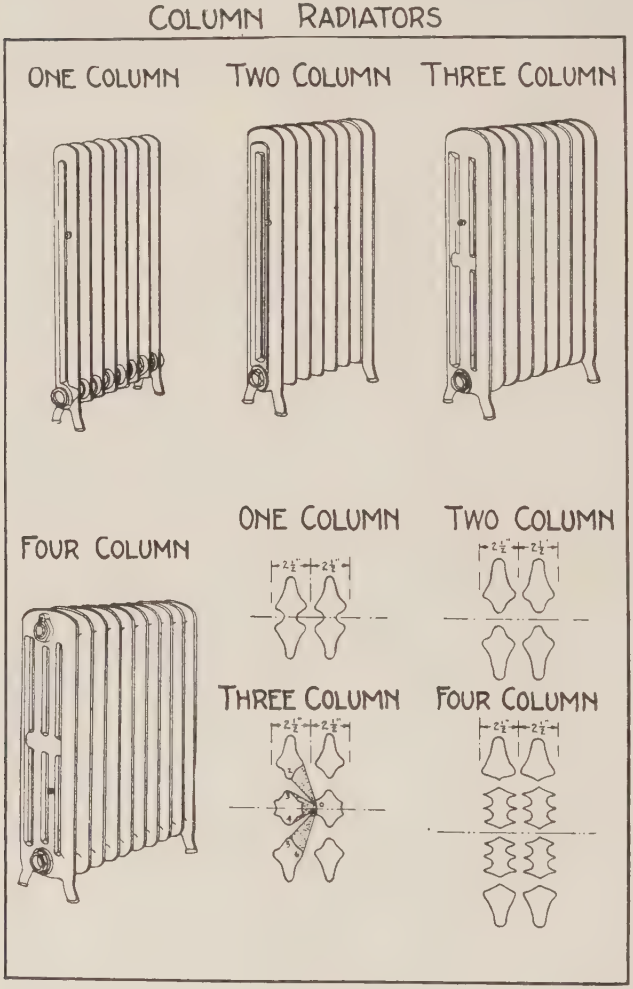


Fig. R-1-4. Column Radiators

two, three and four-column radiators, a column of a radiator being an element of which a radiator section is composed. Each of the cross-section views in the lower right part of Fig. R-1-4 contains two sections with the respective number of columns as noted.

Several sections when united form a radiator. Thus the three-column radiator, shown in Fig. R-1-4, is designated a 9-section 3-column floor radiator. The end sections have legs and hence are denoted as leg sections; the intermediate sections are called loop sections.

Work Problem R-1-5

The sections of cast column radiators are connected by mild-steel or malleable push or screw nipples through which the heating medium may circulate from one to the adjoining section. Fig. R-1-5 illustrates the two types of nipples used, separately and when in place. The malleable nipple, not being subject to corrosion, is generally pre-

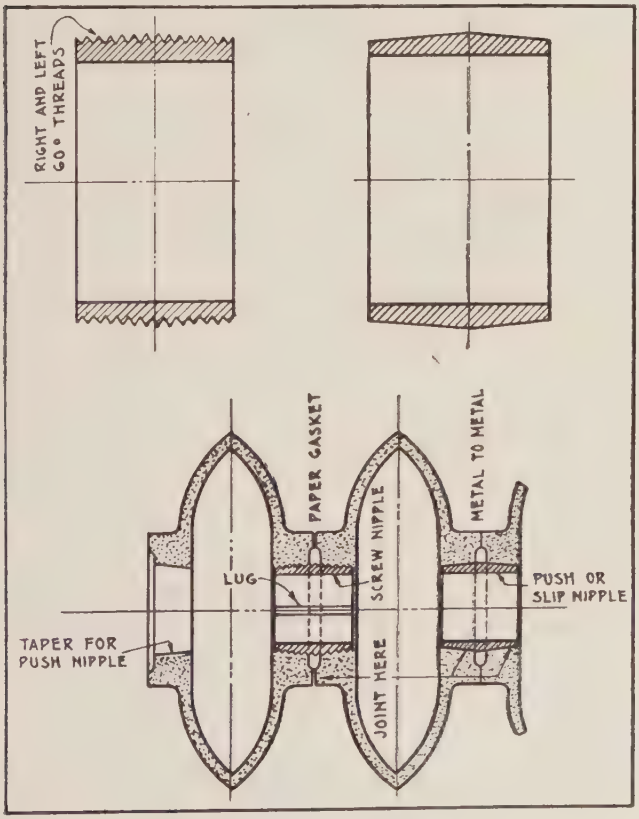


Fig. R-1-5. Screw and Push Nipples Used for Connecting Sections of Radiators

ferred to the steel nipple, although the malleable nipple is subject to defects in casting. When push nipples are used between sections, two to four rods are provided for holding the entire radiator as a unit, the end sections at top and bottom having a web cast between the columns. This web is drilled for the rods threaded at both ends for units with which the sections are drawn and held tightly together.

When screw nipples are used, rods are omitted, since the nipples have right and left-hand threads and a special lug on the inside for drawing the sections together. The nuts are faced and these faced connections fitted with paper gaskets which provide an additional protection against water or steam leakage when the nipples are securely screwed in place. After assembling, the radiator should be tested to a pressure of 85 lbs. per square inch gage.

Work Problem R-1-6

Dimension and capacity data on radiators are most essential when planning an installation. Such data relating to column radiators built by one manufacturer are contained in Table R-1-1 in order to familiarize the student with the use and application of similar data contained in the hand catalogs of all who manufacture this class of material.

Work Problem R-1-7

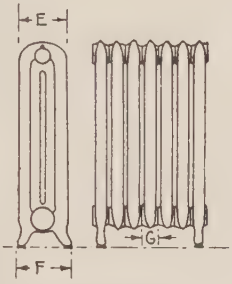
Wall-type radiators, necessarily, fall into the one-column class since they are designed for the least practicable thickness. They are manufactured as a single unit casting in three sizes of 5, 7 and 9 sq. ft. of surface, respectively, or they may be obtained as assembled units having surfaces from 5 sq. ft. upwards, in multiples of 2½ ft. The various size units may be obtained in a variety of combinations to suit conditions calling for either a horizontal or vertical stack arrangement or as ceiling radiation.

Ratings and measurements of wall radiators of the unit-cast type are given in Table R-1-2 for one design and in Table R-1-3 for another design. Fig. R-1-6 shows the characteristics of the unit-cast type with a few of the possible combinations.

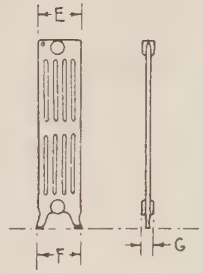
Work Problems R-1-8, R-1-9, R-1-10 and R-1-11

TABLE R-1-1 RADIATOR DATA

Kind of Radiator	Height Ins.	H.S. per Section Sq.Ft.	Measurements Inches E	F	G	Illustrated
One Column	38	3	4 13/32	5 3/8	2 1/2	
	32	2 1/2	4 13/32	5 3/8	2 1/2	
	26	2	4 13/32	5 3/8	2 1/2	
	23	1 2/3	4 13/32	5 3/8	2 1/2	
	20	1 1/2	4 13/32	5 3/8	2 1/2	
Two Column	45	5	7 3/8	8 1/4	2 1/2	
	38	4	7 3/8	8 1/4	2 1/2	
	32	3 1/3	7 3/8	8 1/4	2 1/2	
	26	2 2/3	7 3/8	8 1/4	2 1/2	
	23	2 1/3	7 3/8	8 1/4	2 1/2	
	20	2	7 3/8	8 1/4	2 1/2	
Three Column	45	6	9	9 3/4	2 1/2	
	38	5	9	9 3/4	2 1/2	
	32	4 1/2	9	9 3/4	2 1/2	
	26	3 3/4	9	9 3/4	2 1/2	
	22	3	9	9 3/4	2 1/2	
	18	2 1/4	9	9 3/4	2 1/2	
Four Column	45	10	10 1/2	11 1/4	3	
	38	8	10 1/2	11 1/4	3	
	32	6 1/2	10 1/2	11 1/4	3	
	26	5	10 1/2	11 1/4	3	
	22	4	10 1/2	11 1/4	3	
	18	3	10 1/2	11 1/4	3	
Hospital	45	5	7 3/8	8 1/4	3	
	38	4	7 3/8	8 1/4	3	
	32	3 1/3	7 3/8	8 1/4	3	
	26	2 2/3	7 3/8	8 1/4	3	
	23	2 1/3	7 3/8	8 1/4	3	
	20	2	7 3/8	8 1/4	3	
Window	20	5	12 1/2	12 1/2	3	
	18	4 1/2	12 1/2	12 1/2	3	
	16	3 3/4	12 1/2	12 1/2	3	
	13	3	12 1/2	12 1/2	3	
Corto	38	4 1/2	8	8 3/8	2	
	34 1/2	4	8	8 3/8	2	
	31	3 1/2	8	8 3/8	2	
	27	3	8	8 3/8	2	
	23	2 1/2	8	8 3/8	2	
	19 1/2	2	8	8 3/8	2	



COLUMN RADIATOR



CORTO RADIATOR

Similar information to that for the unit-cast type of wall radiator is given in Tables R-1-3 to R-1-6, inclusive, for the assembled unit section wall radiator built by another firm. The radiators illustrated in connection with these tables are built in two heights, 15 and 22 in. and may be obtained in any desired length in multiples of 2½ ft. of surface from 5 sq. ft. upward. All necessary dimensions are given to enable the student to determine the space requirements for any desired combination.

Work Problem R-1-12

In addition to the forms of radiators already mentioned, there are many so-called special radiators some of which are fast disappearing from the market. Special radiators include the bathroom radiator, the circular radiator, the corner radiator, column radiators without legs, single foot and extra high leg radiators, window radiators, hospital radiators, etc. Most of such types are illustrated in manufacturers' catalogs where dimension and capacity data are given. The student in heating and ventilating work should gradually accumulate for himself a file of manufacturers' catalogs and refer to them frequently. They contain a wealth of reliable and helpful information.

It should be noted in Table R-1-1 that the distance from center to center of sections of the column radiators there shown is given as 2½ and 3 in. This is fairly standard. Specifications prepared for the heating system for hospitals and sanitariums, however, often call for a radiator that is more accessible for cleaning than is the standard column-type radiator. The hospital radiator, with 3 in. between sections instead of 2½ in. is supplied to fill such requirements. Data on this type of radiator are contained in Table R-1-1.

The window-type radiator is built very much lower than the regular column radiator. It may be obtained in the 5 or 7-column type and in various heights suited for installation in front of low window sills or under window seats. Data on this type are also contained in Table R-1-1.

Work Problem R-1-13

TABLE R-1-2

PEERLESS WALL RADIATORS

TYPE	LENGTH INS.	WIDTH INS.	THICKNESS INS.	THICKNESS WITH BRACKETS, INS.	HEATING SURFACE
5-A	16 5/8	13 5/16	2 7/8	3 1/2	5 SQ FT
7A – 7-B	21 7/8	13 5/16	2 7/8	3 1/2	7 SQ. FT.
9A – 9-B	29 1/16	13 5/16	2 7/8	3 1/2	9 SQ. FT.

Allow 1/2" for every bushing.
Allow 1 1/8" for each hexagon nipple used in assembly.
Radiators tapped 1 1/2" supply and return–bushed to suit.

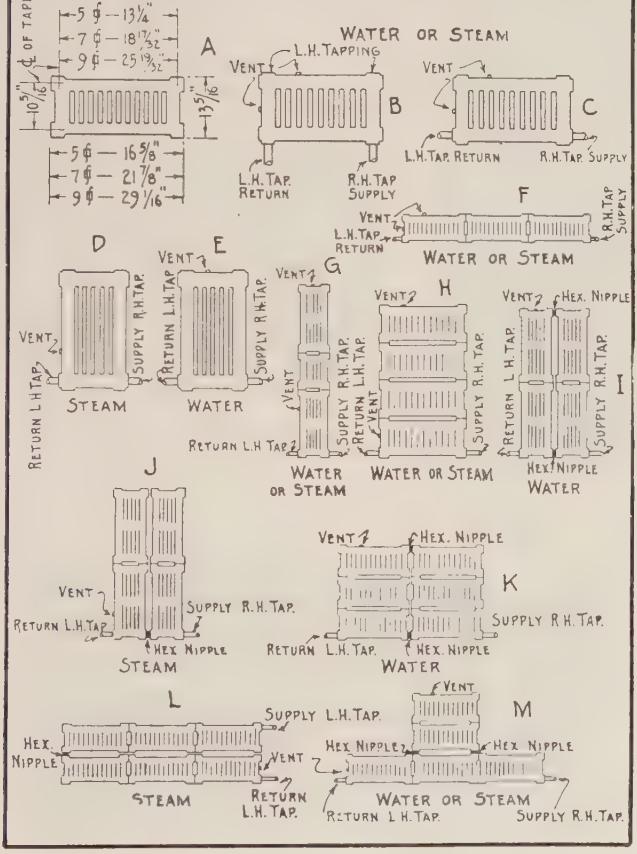
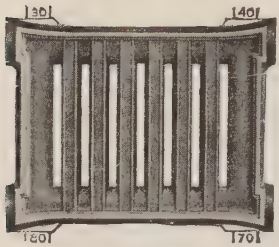
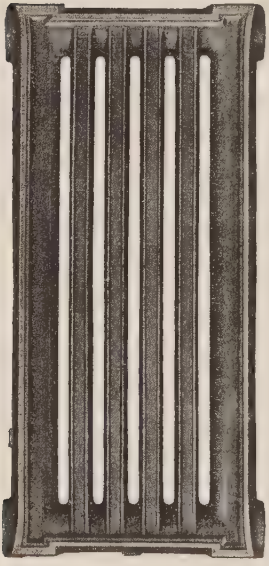


Fig. R-1-6. Wall Radiator (Peerless) Assemblies.

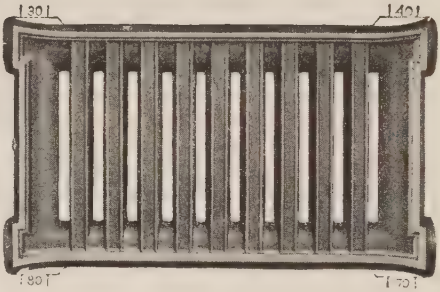


5-A

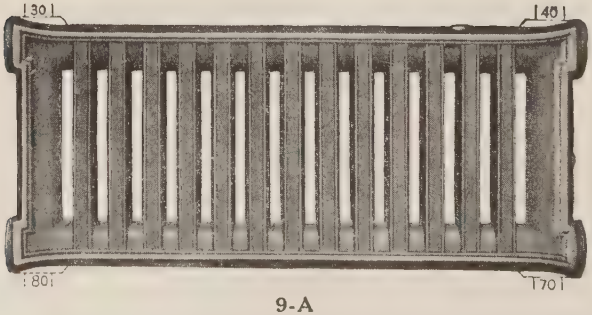
7-B



9-B



7-A



9-A

Courtesy, American Radiator Co.

Wall (Peerless) Radiators

LOCATION OF TAPPINGS } X Supply-One pipe Steam; S Air Vent Steam
YZ Ret. & Supply, Water & Steam; S-1 One pipe
W Air Vent Water; S-2 Two-pipe

RADIATORS-1 TIER HIGH

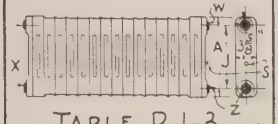


TABLE R-1-3

DIMENSIONS	15 In.	22 In.
A	14 9/16"	21 11/16"
J	11 9/16"	18 11/16"

RADIATORS-2 TIERS HIGH

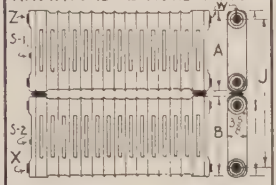


TABLE R-1-4

DIMENSIONS	30-In. 15 15	37-In. 15 22	40-In. 22 22
A	14 9/16"	14 9/16"	21 11/16"
B	14 9/16"	21 11/16"	21 11/16"
I	29 7/8"	37"	44 1/8"
J	26 7/8"	34"	41 1/8"

RADIATORS 3 TIERS HIGH

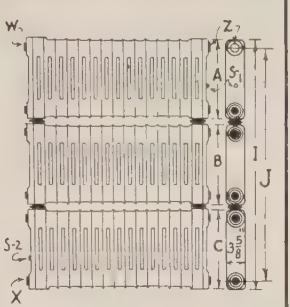


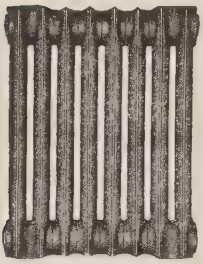
TABLE R-1-5

DIMENSIONS	45 INCH 15 15 15	52 INCH 22 15 15	59 INCH 22 15 15	66 INCH 22 22 22
A	14 9/16"	14 9/16"	14 9/16"	21 11/16"
B	14 9/16"	14 9/16"	21 11/16"	21 11/16"
C	14 9/16"	21 11/16"	21 11/16"	21 11/16"
I	45 3/16"	52 5/16"	59 7/16"	66 9/16"
J	42 3/16"	49 5/16"	56 7/16"	63 9/16"

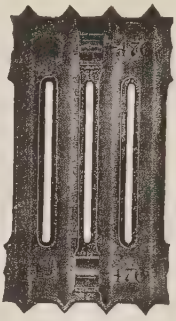
TABLE R-1-6 REGULAR TAPPINGS

RADIATION SQ. FT.	ONE PIPE STEAM	TWO PIPE STEAM	WATER
30 and smaller	1 in.	—	—
31 to 59	1 1/4 in.	—	—
60 and larger	1 1/2 in.	—	—
50 and smaller	—	1 in. x 3/4 in.	1 in. x 1 in.
51 to 119	—	1 1/4 in. x 1 in.	1 1/4 in. x 1 1/4 in.
120 and larger	—	1 1/2 in. x 1 1/4 in.	1 1/2 in x 1 1/2 in.
AIR VALVE	1/8 in.	1/8 in.	1/8 in.
LOCATION OF TAPPINGS	Bottom-one end	1 Tier – bottom opp. ends	
		2,4,6 Tiers-T.& B. same end	
	Must be specified	3,5,7 Tiers-T.& B. opp. ends	

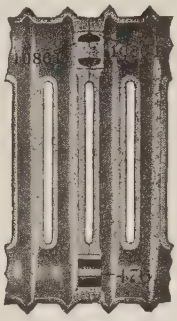
Fig. R-1-7. Wall Radiator (Princess) Assemblies



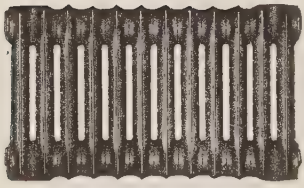
22-Inch Height
10-Foot Radiator
8 Tubes



Water

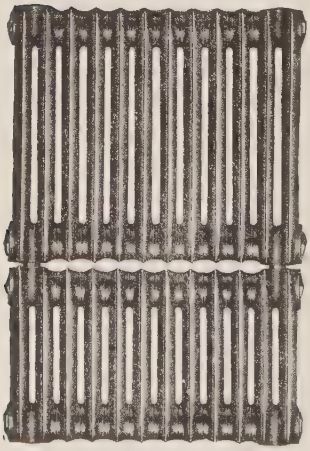


Steam

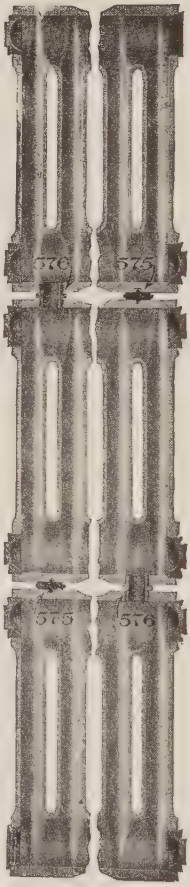


15-Inch Height
10-Foot Radiator—12 Tubes

Two Tiers High



37-Inch Height
25-Foot Radiator—
12 Tubes



Three Tiers High

Courtesy, H. B. Smith Co.

Wall (Princess) Radiators

By special order, manufacturers will supply regular column radiators in various shapes or combinations. Circular radiators may be secured for placement around columns and corner, angle and curved radiators can be secured to fit into almost any corner or bay window. In placing orders for such, it should be accompanied by a template or sketch giving exact dimensions of the space to be occupied and area required.

Column radiators without legs are hung on the wall by means of special brackets. The bathroom radiator is fastened with lag screws or hooks. This radiator is especially suited to rooms where limited space is available and should receive consideration where a system is to be designed for modern bathrooms in hotels, apartments and similar structures where all space is carefully conserved.

Under the fourth designation (medium for heating), radiators are called water radiators and steam radiators. These types differ in construction.

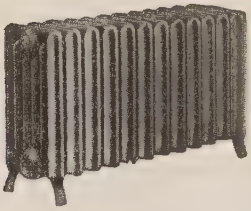
A water radiator consists of sections joined by nipples along both top and bottom, while in a steam radiator connections are made only at the bottom. Tappings for steam radiators are always made at the bottom while water radiators may be tapped for supply at the top or bottom, with return connection at the bottom. Water radiators may be used in a steam system successfully but steam radiators, owing to the lack of inter-connection of sections at the top, are not suited for use with a water circulating system. Water radiators are also used for two-pipe steam and vapor systems. Both types of radiators must be provided with an outlet for discharging the air which enters with the heating medium. A tapping for this purpose is located on the end section at the top on water radiators and slightly above the vertical center on steam radiators.

The manufacturers, however, are gradually discontinuing building steam-type radiators. They are placing two air vent tappings, one located near the top and the other about three-fifths down from the top on the water-type radiator so that it will be suitable for either steam or water.

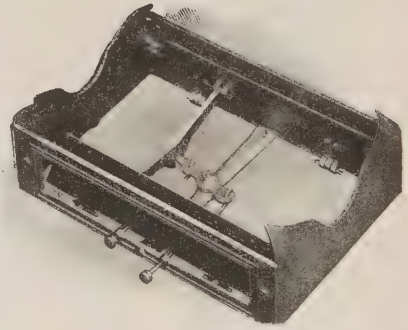
Work Problem R-1-14

Bath Room Radiator

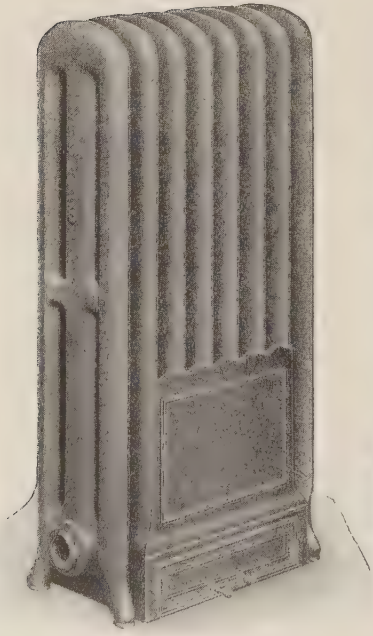
Corto Radiator



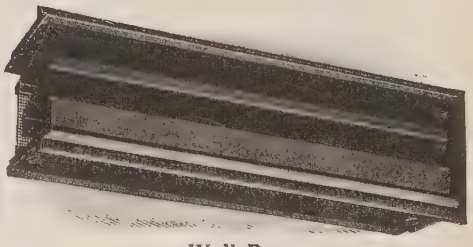
Window Radiator



Ventilating Radiator Base



Ventilating Radiator



Wall Box

Courtesy, American Radiator Co.

Special Types of Radiators

PIPE COIL RADIATORS

While the use of pipe-coil radiators is limited, yet there are many in existence today and will continue to be used for direct radiation in factories, shops and similar buildings where their appearance is not objectionable. The student of heating, therefore, should have a general idea of their use, the names and arrangements of some of the different types of coils.

In Fig. R-1-8, six examples of coil radiators are shown, designating names being given under each illustration. All pipe-coil radiators in which steam will be used must have ample provision for expan-

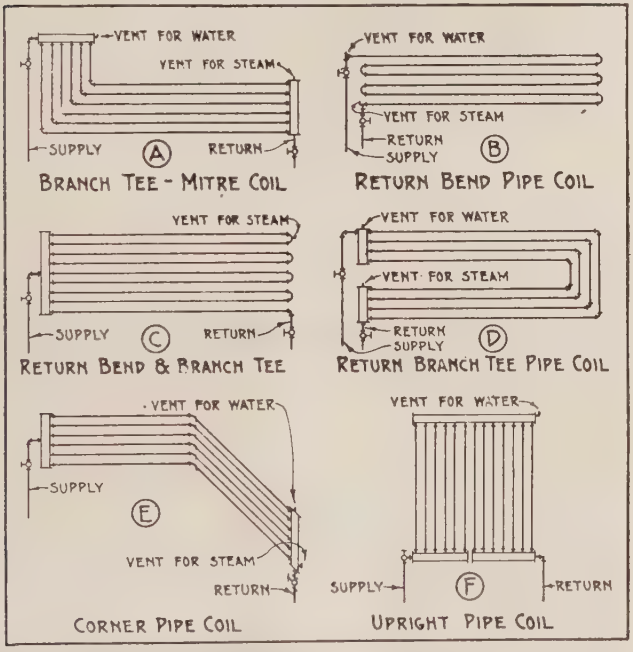


Fig. R-1-8. Examples of Pipe Coil Radiators for Steam and Water Radiation

sion. The branch-tee mitre coil is built of several lengths of pipe connected by right and left elbows to two branch-tees located in vertical and horizontal positions, respectively. Such a coil should always be installed in the position illustrated having the shorter pipe lengths vertical unless it be used as a

ceiling radiator. The air discharge outlet should be placed to suit the heating medium. This type of coil may be used for either steam or water heating.

The return-bend pipe coil shown is not particularly suited for use as a steam radiator since its construction requires that the steam travel through the entire length of a single coil.

Work Problem R-1-15

The return-bend and branch-tee coil provide connections that enable the coils to fill with steam simultaneously and offers a very satisfactory type of coil for steam. This type is not so well suited to use with a water system.

The return branch-tee coil is well suited to positions where vertical wall space is limited. It is constructed by using two branch-tees with an equal number of right-hand elbows and right and left-hand elbows for connecting the pipes to respective outlets on the branch tees. This coil is equally well suited for steam or water heating when due attention is paid to locating the air vent.

Work Problem R-1-16

The corner pipe coil is for use as its name indicates while the upright coil is particularly suited for use as a hot water radiator.

Work Problem R-1-17

WEIGHTS AND INTERNAL VOLUMES OF DIRECT RADIATORS

Frequently it is necessary to know approximate weights and the internal volumes of various types of direct radiators. The volumes of radiators for water heating systems were touched upon in Lesson H-5 of the Water Heating part. The student should refer to and note the application of the volumes there given. Approximate weights are essential in estimating freight and cartage charges. Data on these quantities are contained in Tables R-1-7 and R-1-8. With these tables and the student's work of the Water Heating part, no difficulty should be experienced in solving the following problem.

Work Problem R-1-18

TABLE R-1-7
WEIGHT OF RADIATORS
APPROXIMATE WEIGHT IN LBS. PER SQ. FT. OF SURFACE.

TYPE		LBS. PER SQ. FT.
COLUMN	STEAM	6½
	WATER	7
WALL		7½
CORTO		5¾
WINDOW (5-COLUMN)		7
OTHER DIRECT RADIATORS		6½
INDIRECT RADIATORS		5

TABLE R-1-8
CAPACITIES OF RADIATORS
(INTERNAL VOLUME)

KIND	PINTS (AV.) PER SQ. FT. SURFACE
CAST IRON COLUMN	1.5
CAST IRON WALL	1.65
PIPE, 1-INCH DIAMETER	1.0
PRESSED STEEL	1.0

Before proceeding to the consideration of the steps by which heat is transmitted to space to be heated when radiators are used and to the methods employed for calculating radiating surface required, the student should refer to Fig. R-1-9 in which the classification of radiators is charted. The various divisions discussed are there presented in graphical form for quick and easy reference.

Before proceeding further, the student should go back to the first part of this lesson and read it through carefully with Fig. R-1-9 before him and compare the chart with each of the groupings discussed. In this manner, a comprehensive impression of radiator classification will be made upon his mind.

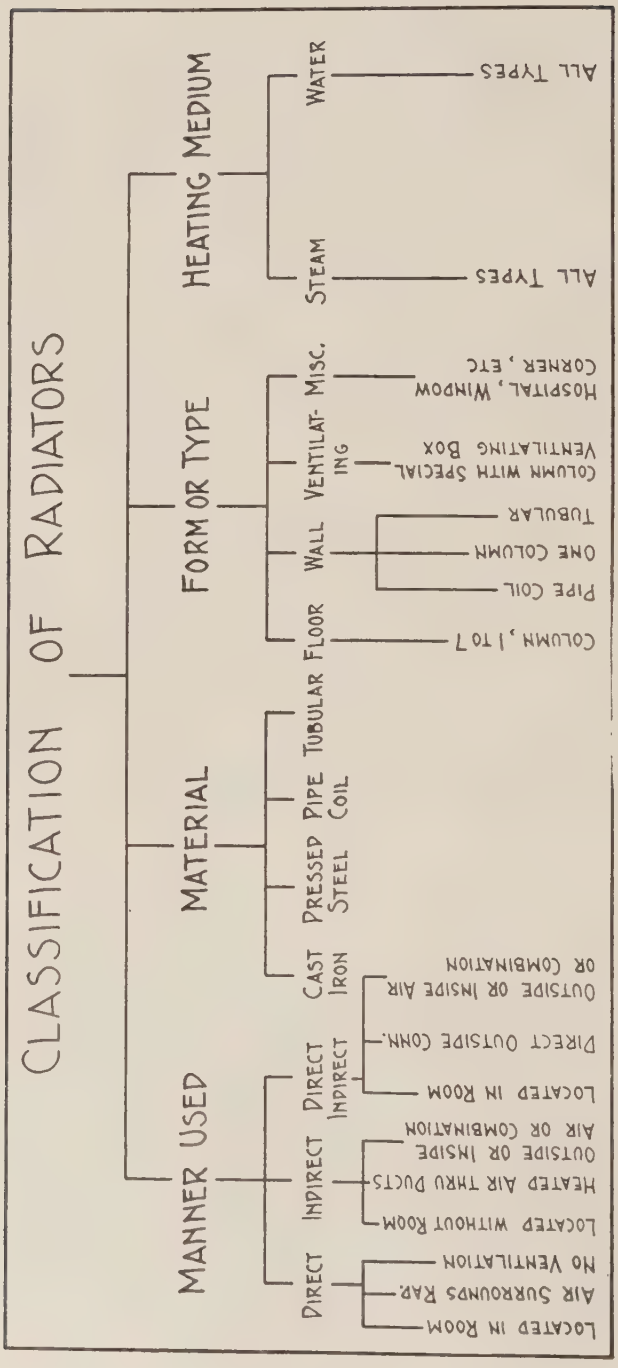

CLASSIFICATION OF RADIATORS
MANNER USED
DIRECT
LOCATED IN ROOM
AIR SURROUNDS RAD.
NO VENTILATION
INDIRECT
LOCATED WITHOUT ROOM
HEATED AIR THRU DUCTS
OUTSIDE OR INSIDE AIR OR COMBINATION
DIRECT-INDIRECT
LOCATED IN ROOM
DIRECT OUTSIDE CONN.
OUTSIDE OR INSIDE AIR OR COMBINATION
MATERIAL
CAST IRON
PRESSED STEEL
PIPE COIL
TUBULAR
FORM OR TYPE
FLOOR
COLUMN, 1 TO 7
WALL
PIPE COIL
ONE COLUMN
TUBULAR
VENTILATING
COLUMN WITH SPECIAL VENTILATING BOX
MISC.
HOSPITAL, WINDOW CORNER, ETC
HEATING MEDIUM
STEAM
ALL TYPES
WATER
ALL TYPES

Fig. R-1-9

FACTORS AFFECTING RADIATION REQUIREMENTS

All types of radiators do not produce equal heating effects per square foot of surface. Consequently, there are a number of factors that must be considered when determining the radiation (meaning square foot of radiating surface) which will be required for maintaining a given space at a desired temperature. The kind of radiating surface, how the radiator will be installed, whether direct, recessed, concealed or indirect, the work the radiator will be required to do and its location in the room are the principal factors that affect the area required. Each of these will be considered in detail in the next lesson.

ESTIMATING RADIATION.

Methods by which the amount of radiation may be estimated may be grouped under four heads enumerated in the reverse order of their dependability:

1. "Rule-of-Thumb" method
2. Dependable rules when applied with experience and judgment
3. Curves and tables for rapid estimation
4. B.T.U. (heat unit) method.

RULE-OF-THUMB METHODS

Rule-of-thumb methods are based on factors derived from "experience" and may vary widely in their values and consequently produce results equally as inconsistent. Practical men are likely to employ different factors in the same formula, making it extremely difficult to lay down definite and fixed values. Unless a person using a certain factor is thoroughly informed as to all the conditions that influence the selection of the proper factor and is possessed of good judgment, errors are liable to result.

In order that the student may have a concrete conception of the application of rule-of-thumb methods for estimating radiation and see how results obtained by their use compare with approved methods, they are here introduced but *the use of rule-of-thumb methods is not recommended.*

Table R-1-9 contains a list of values for use with a simple rule-of-thumb method applied as follows:

Rule: Divide the cubical contents of the space to be heated by a factor from Table R-1-9 and obtain the square feet of direct radiation required.

The work covered in Lesson No. 4 of Part 1, "Fundamentals of Heating," should impress the student with the effect of exposure and infiltration requirements which (except in an arbitrary manner) are practically disregarded in such a method.

Such rules, in the opinion of the author, have but one redeeming feature. They provide a means for roughly estimating the amount of radiation required for a given building upon which to approximate the cost of the heating system, size of boilers, etc., which information is frequently necessary before the exact amount of radiation has been computed.

The B.T.U. method for determining the number of heat units required to maintain a desired temperature in a room for given conditions was fully explained and applied in the second lesson of this course. If the student is not fully conversant with the material there covered, he should review that lesson before studying this lesson.

TABLE R-1-9
FACTORS FOR USE WITH RULE OF THUMB METHOD
(RECOMMENDED FOR APPROXIMATION ONLY)

SPACE TO BE HEATED	CU. FT. PER SQ. FT. RADIATION	
	HOT WATER	STEAM
DWELLINGS		
LIVING ROOMS, ONE SIDE EXPOSED	25 TO 30	45 TO 50
LIVING ROOMS, TWO SIDES EXPOSED	20 TO 30	40 TO 50
LIVING ROOMS, THREE SIDES EXPOSED	20 TO 25	35 TO 45
SLEEPING ROOMS	30 TO 40	50 TO 60
HALLS AND BATH ROOMS	20 TO 30	40 TO 50
PUBLIC BUILDINGS		
OFFICES	30 TO 50	50 TO 75
SCHOOL ROOMS	20 TO 30	55 TO 80
FACTORIES AND STORES	40 TO 60	80 TO 100
ASSEMBLY HALLS AND CHURCHES	60 TO 80	100 TO 125

THE PROPORTION IS BASED UPON A DETAILED BUILDING OF THE AVERAGE CONSTRUCTION AND EXPOSURE, AND OUTSIDE TEMPERATURE ZERO. INDIRECT INCREASES 50 TO 75%. DIRECT-INDIRECT 35 TO 50 % INCREASE.

Work Problem R-1-19

DEPENDABLE RULES

(*When applied with experience and judgment*)

Under this heading, three rules are presented, namely, Mills', Baldwin's and Carpenter's.

MILL'S RULE

(*Steam or Water Radiation*)

First: Calculate the cubical contents of the room in cubic feet.

Second: Calculate exposed wall surface.

Third: Calculate exposed glass surface (include outside doors).

Fourth: Divide result first by 200.

Fifth: Divide result second by 20.

Sixth: Divide result third by 2.

Seventh: Add results fourth, fifth and sixth and obtain the square feet of radiation required for direct steam.

Eighth: Make proper increases to care for exposure and leakage.

Ninth: For direct hot water, increase the result obtained under seventh by 60% before performing eighth step.

Work Problem R-1-20

BALDWIN'S RULE

(*Steam Radiation*)

First: Note the coldest outside temperature common to the locality in which the structure is situated.

Second: Note the inside temperature to be maintained.

Third: Subtract result first from result second.

Fourth: Note the temperature of the steam radiating surface; use 220° F.

Fifth: Subtract result third from result fourth.

Sixth: Divide result third by result fifth and obtain the square feet of radiating surface required for each square foot of glass surface.

Seventh: Calculate the exposed wall surface in square feet.

Eighth: Calculate the exposed glass and door surface in square feet.

Ninth: Divide result seventh by 4 since 4 sq. ft. of wall surface is assumed to be equivalent to 1 sq. ft. of glass surface and obtain the wall surface as equivalent glass surface.

Tenth: Add results ninth and eighth and obtain total equivalent glass surface.

Eleventh: Multiply result tenth by result sixth and obtain the square feet of steam radiation required to heat the room.

Work Problem R-1-21

CARPENTER'S RULE

(*Steam or Water Radiation*)

In the fourth lesson of this course, "Fundamentals of Heating," this rule was given in detail. It was explained and applied by nine separate and distinct steps. The student should review the explanation and application given in the earlier lesson and proceed from the ninth step there given as follows:

Tenth: Divide result ninth by 250 for steam at 5 lbs. pressure or 240 at 2 lbs pressure and obtain the square feet of direct steam radiation required.

Eleventh: Divide result ninth by 150 for hot water and obtain the square feet of direct water radiation required.

Work Problems R-1-22, R-1-23, R-1-24, R-1-25, R-1-26

PART R.

RADIATORS AND RADIATION

LESSON 2.

Heat Emission

HEAT EMISSION.

The rate at which heat is given off from unit area of a radiator in unit time is the emissivity of that radiating surface. The number of heat units (B.T.U.) which will be emitted from one square foot of outside radiator surface during one hour will depend principally upon two factors, (1) the temperature of the heating medium within the radiator and (2) the temperature of the air that surrounds the radiator. Other factors also influence but to a less degree. Each, in turn, will be considered as we progress.

If the heating medium is water which enters the radiator at 180° F. and leaves at 160° F., it is

assumed that the average temperature of the water in the radiator is the mean of these two values or 170° F.

If the heating medium is steam at a pressure of 5.3 lbs. per square inch, its temperature will be 228° F.; if at 2.3 lbs. per square inch pressure, its temperature will be 219.4° F. (assumed 220° F.).

A factor denoting the number of B.T.U. given off by a radiator per square foot per hour per degree difference in temperature between the temperature of the radiator and of the air surrounding it is called the coefficient of heat transmission of the radiator.

If a radiator is assumed to be filled with steam at a pressure of 2 lbs. per square inch and to stand in still air, the temperature of which is 70° F., the range of temperature between the heating media and the air will be 220° F. (steam temperature) — 70° F. (air temperature) = 150° F. This is considered as standard temperature range.

Work Problem R-2-1

Different experimenters have conducted tests to determine the coefficient of heat transmission for different-type radiators for the standard range of temperature. Table R-2-1 contains authoritative coefficients determined by actual tests for a number of different types of radiators for standard conditions. For example, a 38-in., 3-col. radiator has a radiator coefficient of 1.55 or, in other words, it will emit per square foot of surface per degree temperature difference per hour, 1.55 B.T.U. Consequently, with steam at a temperature of 220° F. and the surrounding air at 70° F., the temperature range will be 150° F. and each square foot of surface of this radiator will emit, in one hour, 233 B.T.U. obtained as follows:

1.55 (factor) $\times$ 150 (temp. diff.) = 233 B.T.U.

Work Problem R-2-2, R-2-3

It was developed above that a 38-in., 3-col. radiator under the conditions stated would emit 233 B.T.U. per square foot per hour. Therefore, if the heat loss from a room were 12,450 B.T.U. per hour, there will be required 12,450 (B.T.U. loss) $\div$ 233

TABLE R-2-1
RADIATOR COEFFICIENTS
B.T.U. PER SQ.FT. PER HOUR PER DEGREE

	KIND OF RADIATOR		HEIGHT OF RADIATOR-INS.			
			20 & 22	26	32	38
A	ONE COLUMN	COEFFICIENTS	1.95	1.90	1.85	1.80
B	TWO COLUMN		1.80	1.75	1.70	1.65
C	THREE COLUMN		1.70	1.65	1.60	1.55
D	FOUR COLUMN		1.60	1.55	1.50	1.45

	WALL RADIATORS	COEFFICIENTS
E	LONG SIDE VERTICAL, 5 SQ.FT.	1.92
F	" " HORIZONTAL, 5 SQ.FT.	2.11
G	" " VERTICAL, 7 SQ.FT.	1.70
H	" " HORIZONTAL, 7 SQ.FT.	1.92
I	" " VERTICAL, 9 SQ.FT.	1.77
J	" " HORIZONTAL, 9 SQ.FT.	1.98

	PIPE COILS	COEFFICIENTS
K	SINGLE HORIZONTAL PIPE	2.65
L	SINGLE VERTICAL PIPE	2.55
M	4 PIPES HIGH	2.48
N	6 PIPES HIGH	2.30
O	9 PIPES HIGH	2.12

HARDING & WILLARD - ALLEN & WALKER

(B.T.U. per square foot) = 53.4 sq. ft. of radiating surface required.

Work Problem R-2-4

Reference to Table R-1-1 shows that each section of a 38-in., 3-col. radiator has an area of 5 sq. ft. If 53.4 sq. ft. of radiating surface is required, simple arithmetic indicates the number of sections required. Thus, in this example, $53.4 \div 5 = 10.7$ and an 11-section, 38-in., 3-col. radiator is required.

Work Problem R-2-5, R-2-6, R-2-7

Equivalent lengths and areas of wrought-iron and steel pipes are contained in Table R-2-2. The data contained in this table will be found useful in designing pipe coils. Knowing the total square feet of radiating surface required and the length of pipe in feet per square foot of external surface, for the

TABLE R-2-2
PROPERTIES OF WROUGHT IRON & STEEL PIPE

Pipe Size Ins.	Length of Pipe in Feet per Sq.Ft. of		Area Pipe in Sq.Ft. per Foot Length	Nominal Weight of Pipe Lbs. per Foot	
	External Surface	Internal Surface		Standard	Extra Strong
1/8	9.440	14.150	.106	0.244	0.314
1/4	7.075	10.490	.142	.424	.535
3/8	5.657	7.760	.177	.567	.738
1/2	4.547	6.150	.220	.850	1.087
3/4	3.637	4.635	.275	1.130	1.473
1	2.904	3.645	.344	1.678	2.171
1 1/4	2.301	2.768	.435	2.272	2.996
1 1/2	2.010	2.371	.498	2.717	3.631
2	1.608	1.848	.622	3.652	5.022
2 1/2	1.328	1.547	.753	5.793	7.661
3	1.091	1.245	.918	7.575	10.252
3 1/2	.955	1.077	1.049	9.109	12.505
4	.849	.949	1.179	10.790	14.983
4 1/2	.764	.848	1.310	12.538	17.611
5	.687	.757	1.457	14.617	20.778
6	.577	.630	1.735	18.974	28.573
7	.501	.544	1.998	23.544	38.048
8	.443	.478	2.260	28.544	43.388
9	.397	.427	2.520	33.907	48.728
10	.355	.381	2.820	40.483	54.735

size of pipe to be used, the product of these two quantities will indicate the total length of coil required. If this total length of pipe, in feet, be divided by the number of pipes high that will comprise the coil, the result will indicate the length of the heating unit on the wall.

Work Problem R-2-8

Table R-2-2 contains data useful in checking pipe coil areas. Knowing the size of pipe and total length in the coil, the total radiating surface of the coil may be found by multiplying the total length by the area per square foot for proper size pipe as given in the table.

Work Problem R-2-9

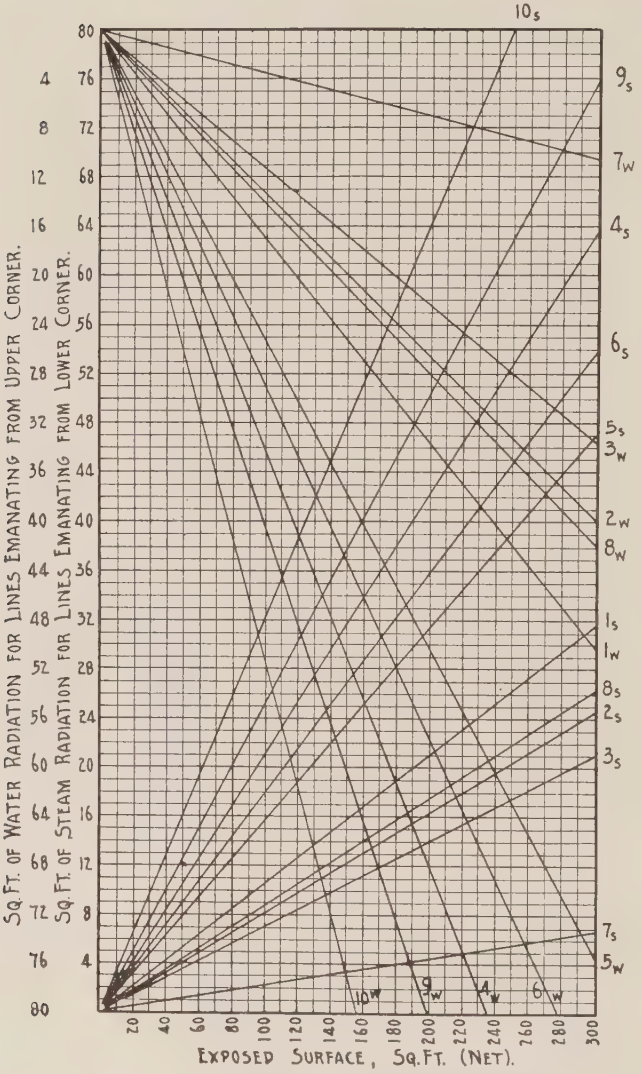


Fig. R-2-1. Curves for Calculating Radiation

1. Brick wall, 8-in., plastered inside.
2. Brick wall, 12-in., plastered inside.
3. Brick wall, 16-in., plastered inside.
4. Concrete wall, 6-in., plain.
5. Concrete wall, 10-in., plain.
6. Frame wall, clapboards on studs.
7. Frame wall, clapboards, paper, sheathing, studs, lath and plaster, with sawdust fill.
8. Roof, 1-in. wood, 5-ply paper, tar and gravel.
9. Roof, shingles on wood strips.
10. Glass, single thickness in wood frame.

TABLE R-2-3
VOLUME FACTORS FOR CHART, FIG. R-2-1.

AIR CHANGES PER HOUR	FACTORS	
	STEAM	WATER
1	0.005	0.008
1½	0.008	0.013
2	0.011	0.017
3	0.016	0.025
4	0.021	0.034

HEAT EMISSIVITY OF RADIATORS FOR OTHER THAN STANDARD CONDITIONS

In the preceding discussion of emissivity, only standard temperature range conditions were considered. The coefficients in Table R-2-1 are based on a temperature difference of 150° F.

If the temperature difference be increased, or decreased, the rate at which heat is emitted will increase or decrease in like manner. The values given in Table R-2-1 may be used for other temperature differences by applying a variation factor accordingly as the temperature range is above or below the standard range of 150° F. This variation factor can be expressed as very nearly 0.2% per degree above or below the standard range of 150° F.

WHEN TEMPERATURE RANGE IS GREATER THAN STANDARD

The temperature of steam at a pressure of 5 lbs. per square inch is 228° F. If a 3-col., 38-in. radiator is filled with steam at this temperature and the room temperature is to be maintained at 50° F., the temperature range will be:

228 (temp. of steam) — 50 (room temp.) = 178° F.

This is 28° above standard range.

The transmission factor for this 178° F. temperature range for the radiator in question would be:

1.55 (factor from Table R-2-1) + [0.002 (variation factor) × 28 (degrees above standard range) × 1.55 (factor from Table R-2-1] = 1.6368 B.T.U. per square foot per hour per degree difference.

Then, each square foot of radiating surface would emit 1.6368 × 178 = 292 B.T.U. per hour.

Work Problem R-2-10

WHEN TEMPERATURE RANGE IS LESS THAN STANDARD

If the temperature range is less than standard, the heat transmission factor will be lower than for the standard range. A lower-than-standard range may exist when the temperature of the heating medium is lower than 220° F. with a room temperature of 70° F., or, as in the case of drying rooms, where the room temperature is considerably above 70° F. without a proportionate increase in the temperature of the heating medium.

In a water heating system designed for supply temperature of 180° F., and a return temperature of 160° F., the average temperature of the heating medium is 170° F. If the room temperature is 70° F., the temperature range will be 170° F. (temperature medium) — 70° F. (room temperature) = 100° F., which is 50° F. below standard range.

The variation will be the same as for a greater-than-standard range but will be applied negatively instead of positively. Thus, for a 3-col., 26-in. direct radiator the transmission factor will become:

1.65 (factor from Table R-2-1) — [0.002 (variation factor) × 50 (degrees below standard range) × 1.65 (factor from Table R-2-1)] = 1.485 B.T.U. per square foot per hour per degree difference. Then each square foot of radiating surface will emit 1.485 × 100 = 148.5 B.T.U. per hour.

Work Problem R-2-11

For ordinary conditions relating to steam plants where the system is designed to use steam at a pressure of 1 to 5 lbs. per square inch for room

temperature of 70° F., the difference in the heat transmission factor for varying temperature differences is seldom considered. In cases, however, of drying rooms and similar places requiring the maintenance of a higher temperature therein, the resulting difference in temperature range will affect materially the radiating surface requirements. In all assigned problems, the student is instructed as to these points or told to use his own judgment.

Work Problem R-2-12

USE OF CURVES FOR CALCULATING RADIATION

Curves, charts and graphs afford a quick and ready means for determining radiation requirements. Such methods, however, should not be employed without a knowledge on the part of the user of the basis for developing the chart or graph. In order that the student may be familiar, in a general way, with reading and using a chart, two are included at this point.

Fig. R-2-1 has been prepared on the basis of a temperature difference of 70° F., and may be used for selecting either steam or water radiating surface so far as the chart may be applied for the existing conditions. The chart contains two sets of lines that radiate respectively, from the lower left and upper left corner of the chart. Those from the lower left corner are plotted for steam radiation; those from the upper left corner are plotted for water radiation. In reading values from any one of the lines, the value should be taken from the proper scale on the left of the chart.

Each of the ten lines, numbered from 1 to 10 inclusive, are applicable to the type of construction enumerated directly below the chart. Values for plotting these lines were based on the heat loss coefficients given in Tables 4 to 9 of the second lesson of the course where their application was fully explained.

The chart of Fig. R-2-1 may be used as follows: Assuming a room having a volume of 2300 cu. ft.; 270 sq. ft. of exposed wall built of brick, 12 in. thick, plastered on the inside; 80 sq. ft. of exposed window surface; a roof consisting of 1-in. wood, 5-ply paper, tar and gravel, of 230 sq. ft. area; that there is no heat loss through the floor and that the

air is changed 1½ times per hour, the surface required for steam radiation is obtained as follows:

The intersection of the exposed wall value line from bottom of chart with line number 2_s is found and by the proper scale on the left, 22 sq. ft. of steam radiation is recorded for the exposed wall; the intersection of the 80 sq. ft. line with line number 10_s indicates 26 sq. ft. of radiation required for the exposed glass; the intersection of the 230 sq. ft. line with line number 8_s indicates 20 sq. ft. of radiation required for the ceiling loss. To heat the air that enters during the air change, the proper value from Table R-2-3 should be used as a multiplier of the cubic contents of the room to obtain the steam radiating area to compensate for this heat loss. Thus for 1½ air changes for 2300 cu. ft., the required area will be $2300 \times 0.008 = 18.4$ sq. ft. The total of all areas as found represents the heating surface required. Thus, for this room, the total surface will be:

	Square feet
For exposed wall	= 22
For exposed glass	= 26
For ceiling loss	= 20
For air change	= 18.4
Total	= 86.4

Work Problem R-2-13

The lines of Fig. R-2-1 for hot water are used in a similar manner as the lower ones are for steam. Attention should be paid to the proper scale on left side and readings made on the outside scale.

Work Problem R-2-14

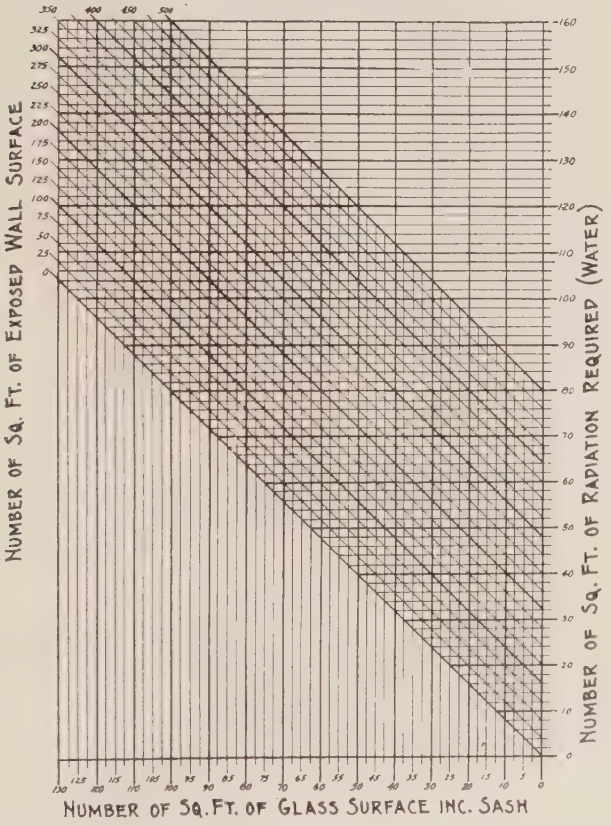
Fig. R-2-2 consists of a chart and factors by which the square feet of water radiation may be selected on the basis of an inside temperature of 70° F. and an outside temperature of 0° F. It is used as follows: Assuming a total exposed wall surface of 225 sq. ft., the diagonal line corresponding to this value is found by the scale at upper left of chart; assuming a total glass surface of 70 sq. ft., the vertical line by scale at bottom of chart, is found; following up the vertical line 70 until it intersects the diagonal line 225, and then moving

horizontally to the scale on the right of the chart, 92 is read as the square feet of water radiation required.

Work Problem R-2-15

If the temperatures are different from 70° F. inside and 0° F. outside, certain multipliers given in the table at bottom of Fig. R-2-2 must be applied to the results read directly from the curves.

Work Problem R-2-16


NUMBER OF SQ. FT. OF EXPOSED WALL SURFACE
NUMBER OF SQ. FT. OF RADIATION REQUIRED (WATER)
NUMBER OF SQ. FT. OF GLASS SURFACE INC. SASH

MULTIPLIERS FOR VARYING TEMPERATURE DIFFERENCES.

DEG. TEMP. DIFFERENCE	MULTIPLIERS	DEG. TEMP. DIFFERENCE	MULTIPLIERS
30	.43	65	.93
40	.57	75	1.08
45	.65	80	1.14
50	.72	90	1.28
55	.79	100	1.43
60	.86		

AMERICAN RADIATOR CO

Fig. R-2-2. Curves for Selecting Amount of Radiation Required

LOCATION OF RADIATORS

The location of radiators is very important. Unless the room has columns or other permanent structures therein, it is generally considered best to

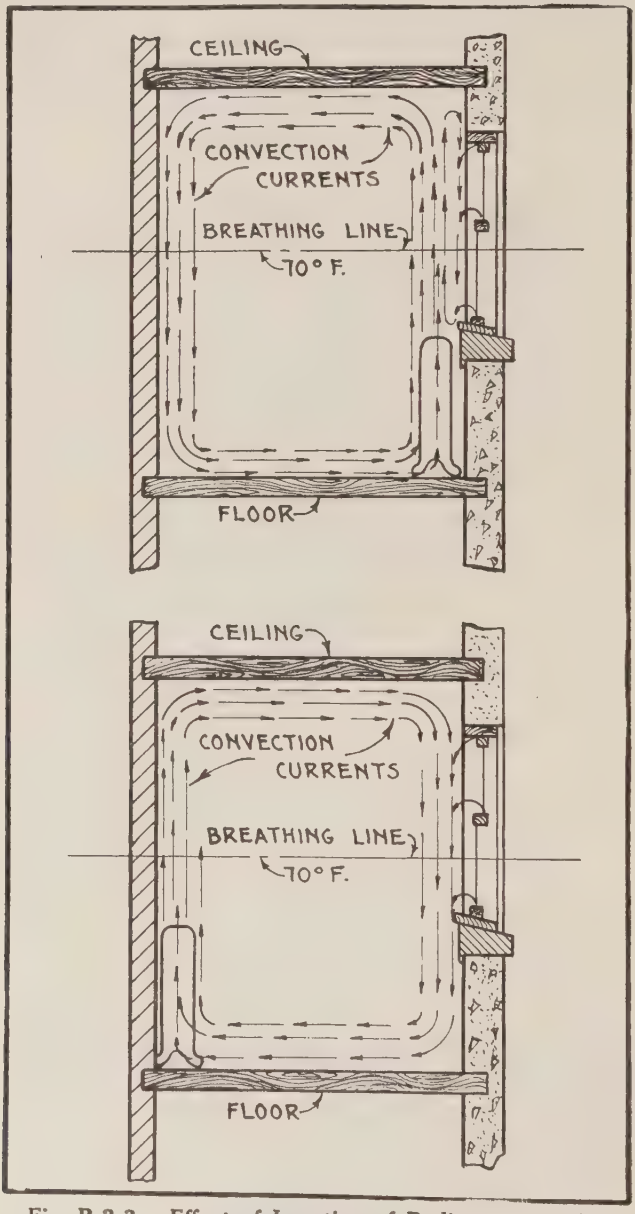


Fig. R-2-3. Effect of Location of Radiator upon Air Movement in the Room

place radiators near the outside walls. But since the effect of position on the heat transmission of a radiator is a subject that has been investigated only to a very limited extent, this should not be considered a hard and fast rule. Experiments that have been conducted from which data are available indicate that the heat loss from a radiator is about the same regardless of whether it is placed at the floor, at the ceiling or in the center of the room; or whether it is placed close to the wall or in the middle of the room.

When possible, it is believed most desirable to locate a radiator in front of a window since cold air enters this point and this location tends toward producing a warmer room on the exposed side for the heat from the radiator heats the wall immediately behind it. If no insulation is placed behind the radiator, this heating represents a small loss. Fig. R-2-3, shows the effect of two locations on air movement. If the radiator is placed along the inside wall, there is a tendency for uncomfortable draft to occur from the cooling effect of the window and outer wall tending to form a down-draft on one side of the room with the effect of the upward movement created by the heat from the radiator on the other side. So, for direct radiators, it is usually best to endeavor to locate them in front of and beneath the windows and adjacent to doors to the outside.

Work Problem R-2-17

EFFECT OF AIR CIRCULATION ON HEAT EMISSIVITY

While no definite data are available (so far as the author is informed) to show by what amount the heat given off by a radiator may be increased by increasing the velocity of the air passing over the radiating surface, yet, the heat carried away by convection can be increased in this manner. It has been observed that heat emission of radiators has been increased approximately 10% in rooms having moving machinery which keeps the air in continuous movement. An electric fan, operating slowly, placed in front of a radiator on the lowest level will assist materially in raising the temperature of a given room in a given time.

EFFECT OF HUMIDITY ON HEAT EMISSIVITY

An increase in relative humidity causes a decrease in the heat given off by a radiator due probably to change in density of the air that passes over the radiator which in turn affects the convection heat loss. Authority states that the B.T.U. emitted per square foot per hour may be reduced from 420 B.T.U. for air at 30% relative humidity to 380 B.T.U. for air at 100% relative humidity.

EFFECT OF PAINTING RADIATORS

Painting affects radiation. The painting, however, affects the radiation constant but has practically no effect upon the convection factor. It is a surface effect so it makes no difference what paints are used as a priming coat. The result of painting depends upon the finishing coat. Therefore, radiating surfaces such as pipe coils or wall coils show more marked effects from painting than do the three or four column radiators which have a comparatively small radiating surface in proportion to convecting surface. The effect of painting may be obtained from the table below which relates to the heat loss from a 2-col. 38-in. radiator, 10 sections long, painted with different kinds of paint and containing steam at a temperature of 215° F. with the radiator in a room at 70° F.

Condition of Surface	B.T.U. per hour per sq. ft.
Cast-iron, bare	240
Painted with aluminum bronze	200
Painted with gold	205
Painted with white enamel	242
Painted with maroon japan	240
Painted with white zinc paint	242
Painted with no-lustre green enamel	230

Work Problem R-2-18

CONDENSATION IN STEAM RADIATORS WHEN STARTING UP

When steam is turned into a radiator, the rate at which condensation occurs (pounds per square foot per hour) increases during the first 10 minutes after which it gradually decreases. At the end of

25 minutes after steam is first admitted, it reaches a normal rate of condensation. Tests have indicated that the maximum condensation may be as much as 3½ times normal condensation and therefore show that the demand made upon a boiler may be very much higher than the normal demand. This will be further discussed in a later part of this course devoted to Steam and Water Heating Boilers.

Work Problem R-2-19

PART R.

RADIATORS AND RADIATION

LESSON 3.

Selection, Location and Installation

RADIATORS AND RADIATION.

CONCEALED RADIATORS

Radiators are often located under seats or shelves or behind grilles of various designs, in order to conceal the radiator or to conserve space. This practice is becoming more and more common in the equipment of many classes of modern buildings. The procedure, however, generally reduces the heating efficiency of the radiator as compared with the same radiator when exposed. Consequently, for enclosed or concealed radiators, a suitable allowance must be made for this decrease in the transmission rate per square foot per hour, per degree difference in temperature. Increased radiating surface must invariably be used when the radiator is concealed.

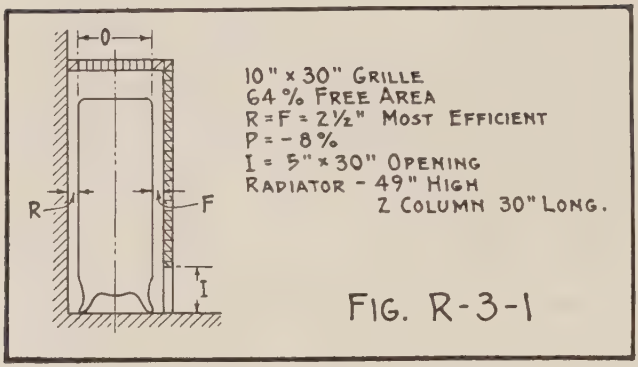
The effect of enclosures, shelves, screens and recessing on the heat-transmission of radiators so installed was rather elaborately investigated several years ago by Professor K. Brabbee and the results of those investigations afford, perhaps, the most reliable factors that are available for determining the proper surface for radiators installed in such manner.

Eight different methods of installation are illustrated in Figs. R-3-1 to R-3-8, inclusive. Each will be taken up separately and a problem assigned to exemplify the application of the factors derived.

For ready comparison, the rate of heat transmission per square foot per hour per degree difference in temperature has been denoted by P for a radiator installed 2½ in. from the wall in still air without enclosure, such as a shelf, grill or screen, and tested under the same conditions as obtained during the experiment with the enclosure in place. Thus, when a grill or screen was used, as shown by Fig. R-3-1, and the transmission rate was determined to be 8% less than with the radiator in the open, this fact may be expressed as P=—8%

The spacing of 2½ in., noted as R and F in installation of Fig. R-3-1, was found to be the most efficient spacing for an enclosed radiator. By increasing or decreasing this spacing, the transmission efficiency was reduced, a greater decrease being noted with an increase in the 2½-in. space. The design of grilles, providing free areas are equal, was shown to have practically no appreciable effect on the rate of heat emission from the radiator.

If the heat loss from a room is 12,560 B.T.U. per hour and a 38-in. 2-col. steam radiator is to be used, installed as shown in Fig. R-3-1, the area required and that upon which to base the pipe size are determined as follows: Assuming the temperature of steam at 220° F., the transmission coefficient (from Table R-2-1) is 1.65; the temperature range is standard, so the total heat emission per square foot will be $150 \times 1.65 = 248$ B.T.U.; but since a radiator installed in the manner indicated suffers a reduction of 8%, the transmission rate



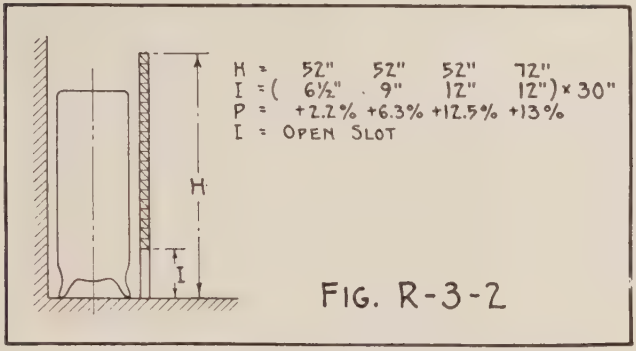
Arrangement with Grille in Front, Closed Top

will be 248 × 0.92 = 228 B.T.U.; thus, 12,560 ÷ 228 = 55.1 as the square foot of surface required; the pipe size to supply the radiator may be based on a radiator of 55.1 sq. ft., transmitting 228 B.T.U. per hour, or upon a radiator transmitting 248 B.T.U. per hour, which in this case would be 12,560 ÷ 248 = 50.7 sq. ft.

Work Problem R-3-1

The efficiency of transmission of a radiator may be increased by installing a screen in front of it with no covering above the radiator, as shown by Fig. R-3-2. It is important with an installation of this type that the air inlet I at the bottom should be amply large. The tests indicated that to extend the enclosure higher than 52 in. had little tendency toward increasing transmission. For example, with a 52-in. screen and 12-in. bottom opening, there was indicated a 12.5% increase, whereas with a 72-in. screen and same-size bottom opening, the increase was only ½% greater, or 13%.

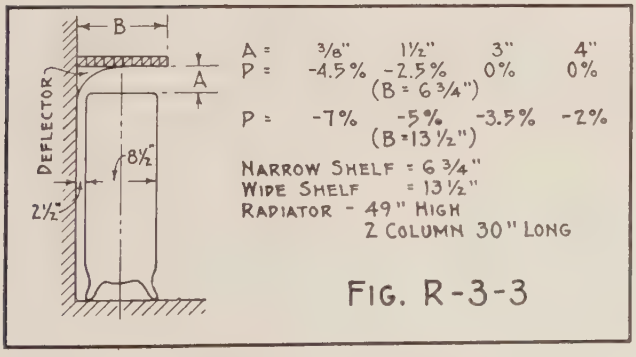
Work Problem R-3-2



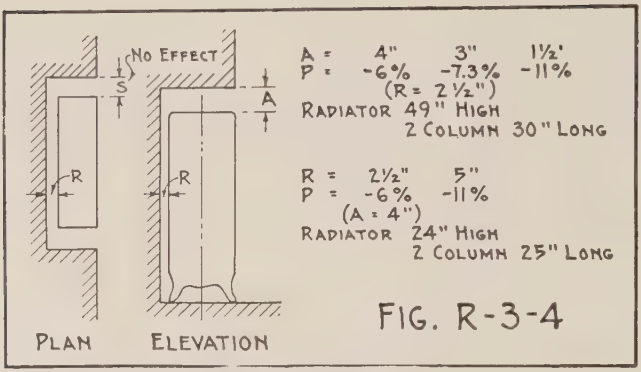
Arrangement with Grille in Front, No Top

Shelves placed at various heights above the tops of radiators, not exceeding 1½ in., reduced transmission efficiency at least 2.5%, for narrow, and 5% for radiators 32 in. high and higher. For radiators up to 26 in. high the reduction in efficiency was more marked, amounting to 5% with shelves 3 in. above top of radiator and as much as 10% when the shelf was only 1½ in. above it. Deflectors, as shown in Fig. R-3-3, had practically no beneficial effect.

Work Problem R-3-3



Arrangement with Shelf Above



Recessed Radiator

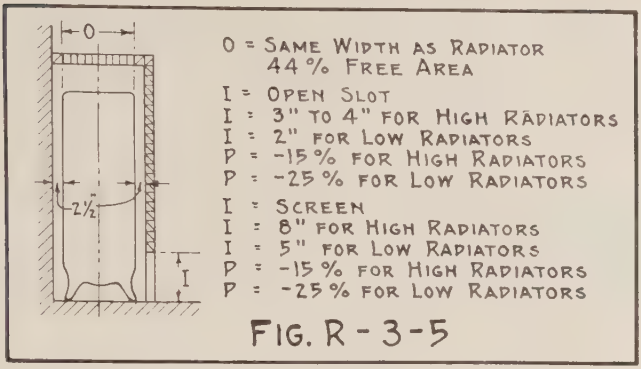
Recessed radiators installed as shown in Fig. R-3-4 have a lower transmission efficiency, the extent of reduction being dependent upon the space at the back between the wall and the radiator and the distance of the under side of the recess above the top of the radiator. The distance from the sides of the radiator to the wall has practically no effect on transmission. The distance "a" in Fig. R-3-4 should never be less than 3 in. while distance R should always be made 2½ in. for maximum efficiency. Under such an installation the loss in transmission, as compared with an openly-installed radiator, would be 8% ; for other distances, as given in Fig. R-3-4.

All of the data as to effect of recesses, grilles, etc. covered in this lesson apply to water as well as steam radiators.

Work Problem R-3-4

Radiators installed as in Fig. R-3-5 having enclosures with various sizes of outlet screens at the top of the enclosure suffer a reduction in radiation. With a screen at the top of the enclosure having the length and width of the radiator, with a 2-in. open slot the same length as the radiator, the reduction will be about 15%. Slight improvement is obtained with screens wider than the radiator. Screens narrower, however, cause further reduction at the rate of about 5% in addition to the 15% for every inch the screen is narrower than the radiator.

Work Problem R-3-5


O
2½"
I
O = SAME WIDTH AS RADIATOR
44% FREE AREA
I = OPEN SLOT
I = 3" TO 4" FOR HIGH RADIATORS
I = 2" FOR LOW RADIATORS
P = -15% FOR HIGH RADIATORS
P = -25% FOR LOW RADIATORS
I = SCREEN
I = 8" FOR HIGH RADIATORS
I = 5" FOR LOW RADIATORS
P = -15% FOR HIGH RADIATORS
P = -25% FOR LOW RADIATORS
FIG. R-3-5

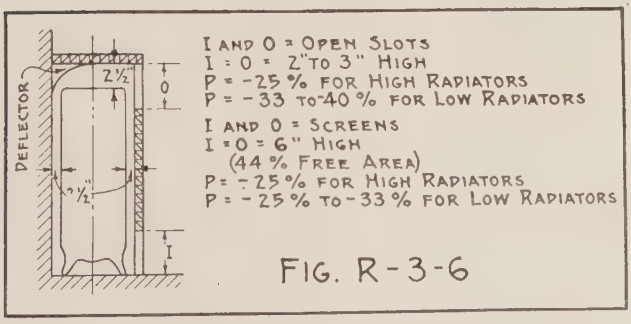
Arrangement with Grille in Front, Variable Sized Outlet at Top

Open-inlet slots of various sizes cause less reduction when used with high radiators, 32-in. and above, than with low radiators. In each case, reduction in transmission occurs as noted in Fig. R-3-5.

Work Problem R-3-6

Screened inlets in place of open slots, for equal areas, exert about the same effect on radiation transmission for high as well as for low radiators. They reduce the transmission in amounts as indicated in Fig. R-3-5.

Work Problem R-3-7


DEFLECTOR
2½"
O
½"
I
I AND O = OPEN SLOTS
I = O = 2" TO 3" HIGH
P = -25% FOR HIGH RADIATORS
P = -33 TO-40% FOR LOW RADIATORS
I AND O = SCREENS
I = O = 6" HIGH
(44% FREE AREA)
P = -25% FOR HIGH RADIATORS
P = -25% TO -33% FOR LOW RADIATORS
FIG. R-3-6

Arrangement with Grille in Front Having Openings at Top and Bottom; Shelf Above Radiator

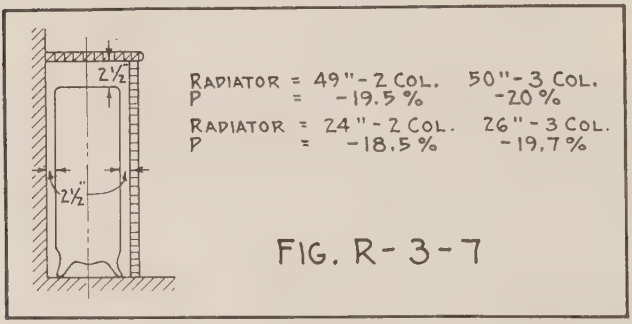
Fig. R-3-6 shows an enclosed radiator with open slots at top and bottom of enclosure and with a space of 2½ in. above the radiator. Again, a re-

duction in efficiency occurred amounting to about 25% for high radiators and 33% for low 3-col. and 40% for low 2-col. radiators. The slots should always be as long as the radiator and 2 to 3 in. high.

Work Problem R-3-8

Perforated sheet-steel fronts, with top of exposure 2½ in. above the radiator, reduces heat transmission for 2-col. and 3-col., both high and low radiators, by about 20%. See exact percentages given in Fig. R-3-7.

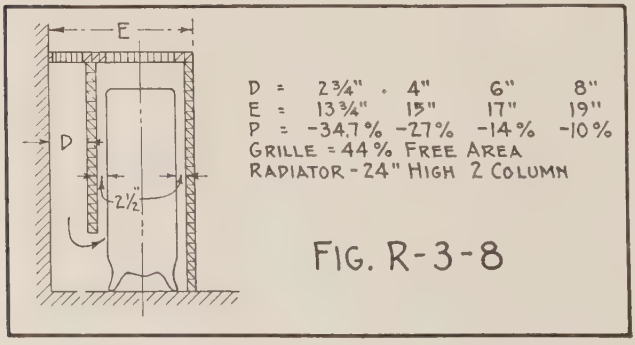
Work Problem R-3-9



Arrangement with Perforated Grille in Front; Shelf Above Radiator

Window recesses or seats, with an air supply taken through the top of enclosure, reduces radiation of heat by 30%, for high, and about 40% for low radiators. See Fig. R-3-8. The space D can seldom be made greater than 3 to 4 in. wide.

Work Problem R-3-10



Arrangement with Solid Screen in Front and Rear and Openings in Top Cover for Air Inlet and Outlet

SELECTION, LOCATION AND INSTALLATION OF RADIATORS

The selection, location and installation of radiators involves a consideration of many factors in which the experience and judgment of the engineer plays no small part and in which the wishes of the owner, particularly if the installation be in a residence, should have due consideration insofar as whims or desires may not be allowed to conflict with good design.

The type of system, whether it be steam, water or vapor, immediately fixes the kind of radiators that will be used. The adaptability of steam and water radiators was covered in a preceding lesson of this part.

The character of the structure and its use will influence, to a considerable extent, the decision as to the type of radiator to use. Cost, availability and facility of installation are also important considerations. Radiators with feet are generally easiest to install. They are obtainable as a unit and require only placement in the selected position. The 38-in., 3-col. radiator has grown in many localities to be considered more or less standard. Consequently, it is generally carried in stock and often is lower in cost per square foot of heating surface than other sizes or kinds of column radiators.

Column radiators are commonly used for most of the rooms in residences. In the living room column radiators are generally placed directly in front of the windows and are of a height slightly less than the height of the sill above the floor. When the window sills are low or seats are built in front of the window, a window radiator will be found necessary. The effort should be to locate the radiator so that air which leaks in will have its temperature raised before it reaches the frequented part of the room.

Low-column, or window, radiators are often used in dining rooms and kitchens and should be located as explained above. The small amount of available wall space in kitchens often makes it necessary to locate the radiator in this room under the drain board or sink.

Halls and bedrooms are usually supplied with column radiators. In the hall, narrow high radiators are generally employed. They should be located so that incoming air will be heated before passing into the main part of the hall and thence to the rooms connecting therewith. In the bedrooms, wall space is frequently at a premium, which relegates the radiator to the window position which is really the proper place for it.

Sun parlors and breakfast rooms generally require the use of low or wall radiators placed to care for infiltration in the sun parlor and to be the least in the way in the breakfast room.

Bath rooms require, usually, tall radiators of few sections of the narrow-column type, or a wall radiator which can be placed under the lavatory or in other space that would not otherwise be utilized.

For apartment houses, the same applications hold as for residences.

For office rooms in large office buildings, suitable column radiators are generally employed, while in the corridors on first floors, column radiators are placed just within the door or, if the building has a vestibule, the radiator is placed there so as to raise the temperature of the outside air previous to its entrance into the building proper. On other floors, spaces in front of windows, in juts between columns, or equal distribution along the wall in long corridors is the usual custom.

A large window radiator placed on the floor in front of the show window, with column or wall radiators along the rear wall, are commonly used for small stores. Large stores demand a tempering of incoming air at the doors, as with large office buildings, and therefore require installation of radiators in similar places. In the store room proper column radiators are frequently placed around columns or in the center of wide aisles, with suitable shelves above the radiator on which goods may be displayed.

For hospitals and sanitariums, column radiators with greater distances between sections and column radiators without legs, which may be attached to the wall, are generally specified as they are more accessible for cleaning.

Factories afford many opportunities for the ingenious use of wall radiators while the use of wall radiators, in turn, provide a solution for many problems arising in factory heating where direct radiation is to be used. When wall space is available, units of wall radiators may be conveniently assembled on the floor and lifted into position directly below windows or at other points along the wall. With limited wall space, wall radiators may be installed in double rows. Suitable brackets are available for either single or double-row mounting.

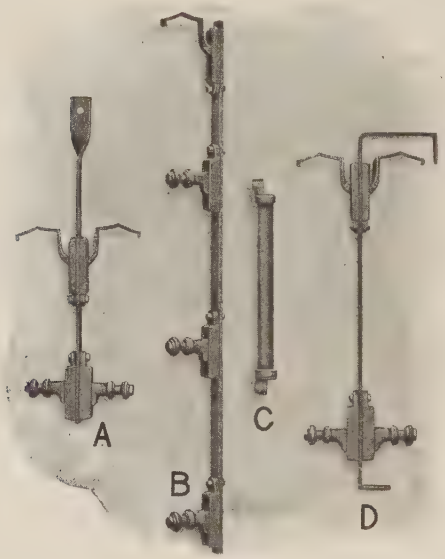
Where floor and wall space in factories is demanded for benches, machinery, platforms, etc., wall radiators may be hung from girders, in roof bays, light wells or other more or less unused space by means of supports provided for such installation.

Special applications of wall radiators are many of which the following are a few: as partitions, by standing several sections in suitable leg brackets placed in an open space and attaching (by special bracket) a shelf above; to partition large floor areas for present and future needs; to form the under-floor of drying rooms; as the base support for tanks holding liquids that must be kept at a workable temperature; under benches in greenhouses, etc.

In residences, apartments, and large offices, it is advisable, where manually controlled, to divide the heating surface into two radiators, making the surface of one radiator equal to twice that of the other so that one, two or three-thirds of the total surface may be employed, depending on outside temperature changes.

ROUGHING IN REQUIREMENTS

During the construction of new buildings and before walls, floors and ceilings are closed, the heating contractor must install certain of his piping. This requires that the stubs left projecting through the floor must be the proper distance from the wall and the center-to-center distance, such as to accommodate the radiator specified for the particular location.



Courtesy of American Radiator Company.

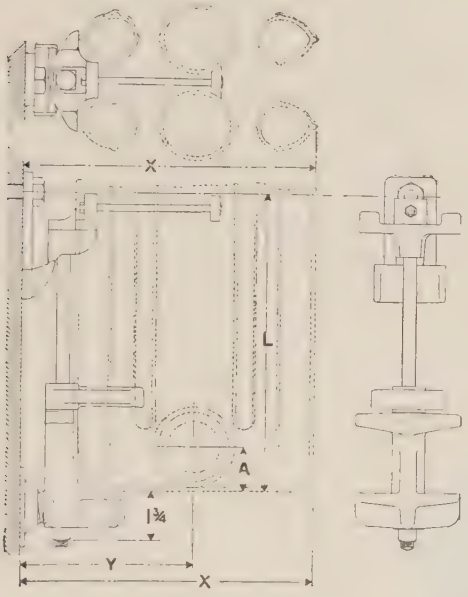
Adjustable Brackets for Wall Radiators.

A For ceiling suspension, holding duplex radiators.
B For supporting wall radiators, one above the other.
C For supporting wall radiators hung flat and parallel to the ceiling.
D For supporting duplex radiators from floor and wall.

Bracket for Single Row of Radiators

Bracket for Double Row of Radiation

The designing engineer, therefore, should include on his layout such needed dimensions. In establishing the proper distances, it is necessary to take into account the length of the radiator over the bosses of the tappings of the end sections and spaces allowed for bushings, elbows and valves.



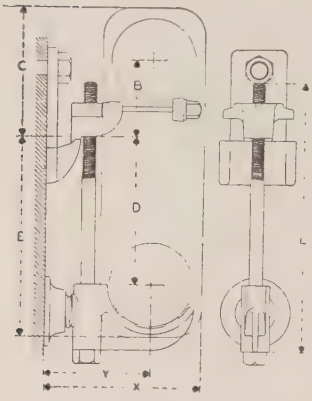
Courtesy, H. B. Smith Co.

Bracket for Column Radiators

DIMENSIONS

	Single Column	Two Column	Three Column	Five Column	
X	7¼"-7¾"	9" -9½"	11" -11½"	14" - 14½"	
Y	4⅝"-5⅛"	5½"-6"	6½"-7"	8" - 8½"	

Height	45"	31" -37"	22" -25"	16"-19"	12"-14"
Length of Rod	25"	21"	15½"	11"	7¾"
L	21⅞"-24⅜"	17⅞"-20⅜"	12⅜"-14⅞"	7⅞"-10⅜"	4⅝"-7⅛"
A	1 1/16"	1 1/16"	1 1/16"	1 1/16"	1 1/16"



Bracket for Wall Radiator

DIMENSIONS

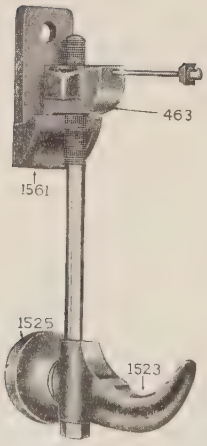
15 in. Radiator

B—5 3/4 in. to 3 3/4 in.
C—7 1/4 in. to 5 1/4 in.
D—5 3/4 in. to 7 3/4 in.
E—7 1/4 in. to 9 1/4 in.
L—11 in.
X—5 5/16 in. to 5 13/16 in.
Y—3 1/4 in. to 4 in.

22 in. Radiator

B—6 1/4 in. to 8 1/4 in.
C—7 3/4 in. to 9 3/4 in.
D—10 1/2 in. to 12 1/2 in.
E—12 in. to 14 in.
L—16 1/4 in.
X—5 5/16 in. to 5 13/16 in.
Y—3 1/2 in. to 4 in.

Courtesy, H. B. Smith Co.



Courtesy, H. B. Smith Co.

Wall Bracket for Wall Radiator (Princess)

Courtesy, H. B. Smith Co.

Wall Bracket for Column Radiator (Princess)

LENGTH OF COLUMN RADIATORS

Table R-1-1 contains data on column radiators; measurement "G" indicating the width of each section for the various kinds of column radiators included in the table. Thus a 10-section, 3-col. radiator would have an overall length of 10 x 2½ (inches per section) = 25 in.

Work Problem R-3-11

BUSHINGS AND REQUIRED SPACE ALLOWANCE

End sections of column radiators are usually tapped 1½ or 2 in. at the top and 2 in. at the bottom. Therefore, it is necessary to use bushings when pipe smaller in diameter than the tapping is to be connected thereto. The bushings, when screwed into the end sections of the radiators, project, requiring that allowance be made and a distance added to the radiator overall length. It is customary to allow ½ in. for each bushing.

If the radiator is to be connected for one-pipe steam or for water circulation, with supply and return connected on the same side, ½ in. should be added to the overall length of the radiator to allow for the bushing. If the radiator is to be connected for two-pipe steam or for water circulation with supply and return connected on opposite ends, it would be necessary to increase the overall length 1 in. to care for bushing projection.

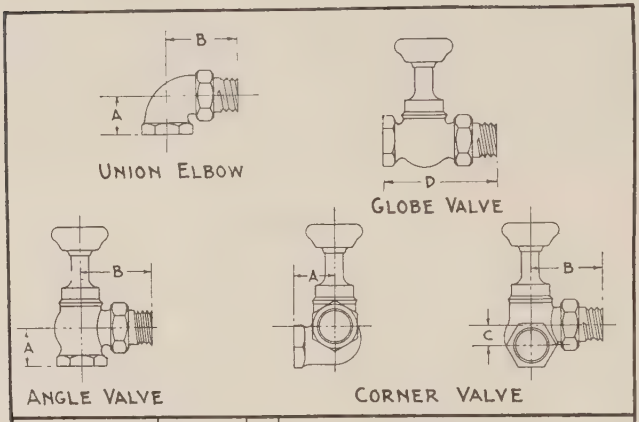
Work Problem R-3-12

VALVES AND REQUIRED SPACE ALLOWANCE

Steam radiators are usually connected to the piping system by one or two valves and water radiators are connected by a valve and a union elbow. All radiator valves are equipped with a union connection.

Table R-3-1 contains roughing-in measurements, as presented by one manufacturer, for radiator valves and elbows. Similar measurements by other manufacturers will most likely differ slightly. It is important, therefor, in practice, to select the

TABLE R-3-1—ROUGHING-IN MEASUREMENTS FOR RADIATOR VALVES AND UNION ELBOWS



	Pattern	Meas.	Size - Ins.					
			½	¾	1	1¼	1½	2
Steam Valves	Angle	A	1¼	1 3/8	1 5/8	1 7/8	2 3/32	2 ½
		B	2 13/32	2 3/4	3 3/32	3 7/16	3 7/8	4 21/32
	Corner	A	1¼	1½	1 3/4	1 31/32	2 11/32	2 5/8
		B	2 13/32	2 7/8	3 ¼	3 ½	4	4 25/32
		C	9/16	¾	13/16	15/16	1 5/16	1 17/32
	Globe	D	3 ¾	4 3/16	4 11/16	5 3/8	6 1/16	7
Water Valve	Angle	A	1	1 3/16	1 13/32	1 5/8	1 27/32	2 19/64
		B	2 7/16	2 3/4	3 1/16	3 7/16	3 15/16	4 9/16
Union Elbow		A	1¼	1¼	1½	1 21/32	2	2 9/32
		B	2 13/32	2 5/8	3 3/16	3 3/8	3 ¾	4 17/32

make of valves that will be used before determining and establishing the overall roughing-in measurements.

The male end of the valve connects with the radiator, while the female end connects with the piping. There is likely to be differences in the distance that radiator valves will set in the bushings when tight. For roughing-in work it becomes necessary to assume this measurement. Values often used by fitters are ½ in. for connections ranging from ½ in. to 1¼ in. in diameter and ⅝ in. for 1½ and 2-in. connections.

Work Problem R-3-13

When estimating the space required for a radiator with connections, due allowance must be made for installing the valve, remembering that there

must be sufficient clearance to permit turning the valve through a full circle when screwing it into the stub. Thus, an angle valve having a "B" measurement of 3-7/16 in. (Table R-3-1) required at least twice this distance for installing unless the union is removed from the valve. This may be done, in which case the space required will be considerably less.

WIDTH OF COLUMN RADIATORS

A column radiator should not be set closer than 2½ in. from the wall for best service so that a free circulation of air will be permitted behind it. This minimum distance should be kept in mind when selecting the type of radiator to be used for a given location, specially where floor space is limited. The fitter should be informed for in nearly all new buildings the piping must be installed quite a time before the radiators are set, requiring that the distance from the finished wall to the center line of the radiator tapping be definitely established.

Widths of various column radiators are noted as measurement "E" in Table R-1-1. The distance across the feet (measurement F) is usually a little greater than "E" but this additional width can usually be disregarded. The various needed distances may be obtained as follows:

To find the projecting distance of a given radiator from the wall: 10½ in. (4-col.) + 2½ in. (distance from wall to back of radiator) = 13 in.

Work Problem R-3-14

To find the distance from the finished wall to the center line of tapping or to the center of the stubs: 10½ in. (4-col.) ÷ 2 (one-half width of radiator) + 2½ in. (distance from wall to back of radiator) = 7¾ in.

Work Problem R-3-15

Column radiators, when hung on the wall by means of concealed brackets and wall radiators, usually set 1¼ in. to 1¾ in. from the wall. This distance will vary depending upon the type of radiator and bracket used. Manufacturers' catalogs contain measurements suited to the respective bracket used.

Work Problem R-3-16

HANDLING AND INSTALLATION

Care should be exercised in the handling and installation of all radiators. When delivered at buildings under construction, they should be protected against the possibility of dirt, sand, shavings or other foreign matter getting in through the tapped openings, to cause circulation troubles after the radiator is set and connected.

Broken or strained nipples with resulting leaks are liable to show up where long assembled units are ordered, handled and installed. A radiator unit weighing in excess of 1,000 lbs. should never be ordered Several smaller units, with combined areas equal to that required connected on the job, are cheaper to handle and afford greater all round satisfaction when used.

Work Problem R-3-17

PART S.

STEAM HEATING SYSTEMS

LESSON 1.

Properties of Steam

STEAM HEATING SYSTEMS.

Before proceeding to a consideration of the several different steam heating systems, it is essential that the student have a knowledge of the nature and properties of steam and be familiar with the use of a steam table.

Water may exist in three distinct forms, namely,—as a solid, as a liquid, and as a gas depending upon conditions of temperature and pressure.

The temperature of water in any one of these states depends upon the pressure. If the pressure be assumed the same for all the conditions, then, at low temperature (below 32° F.) water is in the solid state as ice; between 32° and 212° F. it is in the liquid state as water; at 212° F. it is in the gaseous state as steam. It should be duly impressed

upon the mind of every student that water may exist at a temperature of 32° F. in the solid or liquid state and at a temperature of 212° F. in the liquid or gaseous state. The student should review that section of the first lesson in which was discussed "Latent Heat as Applied to Water" and his approved solution of work problem No. 10 assigned with that lesson.

To generate steam, heat must be added to water so as to raise its temperature to the boiling point corresponding to the pressure to which the water is subjected during the application of heat thereto. If heat is applied to a vessel partly filled with water at a temperature somewhat below a boiling point, the temperature of the water will increase until a definite point is reached at which small particles of water will be changed into steam appearing as small bubbles. These bubbles rise through the mass of water and finally escape from the surface. The water is then boiling.

If the water is heated in a vessel open to the atmosphere, the water will be under atmospheric pressure and the temperature of boiling will be 212° F. If, on the other hand, a closed vessel is used so that as the application of heat is continued, the water will be under a pressure greater than atmospheric pressure, boiling will not commence until the temperature has reached a point above 212° F., that point depending upon the pressure built up within the vessel. In similar manner, if the pressure on water in a closed vessel is reduced below atmospheric pressure and heat is applied, boiling will commence at a temperature below 212° F.

Consequently, the temperature at which water boils depends upon the pressure within the containing vessel; or, in other words, raising the pressure raises the boiling point, and lowering the pressure, lowers the boiling point.

Work Problems S-1-1, S-1-2

KINDS OF STEAM

Strictly speaking, steam is the vapor which arises from water in an open vessel when the water is at a temperature of 212° F. It is a colorless and hence invisible gas.

Practically, steam is designated as *saturated steam* and *superheated steam.* Saturated steam may be *dry saturated steam* or *wet steam.* It is *dry saturated steam* when it contains no water in suspension and its temperature is that of the boiling point corresponding to its pressure. Dry saturated steam from which a part of the contained heat has been taken, becomes *wet steam.* In general, *saturated steam* is steam which is in contact with the water from which it is formed and carries with it a portion of its moisture. Thus, most heating boilers generate *saturated steam* containing moisture and the heating medium with which we will deal in this section of the course is really a mixture of water and steam. *Superheated steam* is that which has been removed from contact with the water from which it was formed and has been further heated so that it has a temperature above that at which it was generated. *Superheated steam* may become *saturated steam* by the addition of water in such quantity as to employ completely the superheat in the steam to evaporate the water added. Vapor is steam at a pressure equal to or slightly above atmospheric pressure. Vapor heating systems, therefore, are *very* low-pressure steam systems.

Work Problem S-1-3

HEAT USED TO FORM STEAM

After steam has been superheated to a temperature considerably above the boiling point, the relations of its pressures, volumes and temperatures follow very closely the laws of a perfect gas. Saturated steam, therefore, is not a perfect gas, so its pressure, volume and temperature relations are not determinable by a simple thermodynamic law, but must be established from results of experiments.

Such experiments have been conducted and elaborate tabulations, called steam tables, have been compiled. Before passing to the use and application of the data given in a steam table, a thorough knowledge should be had of certain terms and quantities which form a part of such a table.

If 1 lb. of water at a temperature of 32° F. is converted into superheated steam at any pressure, the total heat required to cause this conversion is used for three distinct purposes and is designated according to the purpose it serves.

First: The temperature of the water is raised from 32° F. to the boiling point and the heat required to do this is called the *heat of the liquid.*

Second: The pound of water is changed from water at the temperature of the boiling point to dry saturated steam at the same temperature and the heat required to do this is called the *latent heat of vaporization.*

Third: The pound of steam at the boiling temperature is raised in temperature to the final temperature of the superheated steam and the heat required to do this is called the *heat of superheat.*

Work Problem S-1-4

As there will be, in this course, practically no application of the third quantity, heat of superheat, it will not be further considered. The first and second heat quantities, however, are important and will be considered in detail.

If the temperature of a quantity of water is raised, there will be an extremely small increase in volume and, thermodynamically, a small quantity of the heat required to raise the temperature will be consumed in producing this change in volume. Practically, however, this quantity is so small that its use for this purpose may be neglected and all the heat of the liquid may be taken for increasing the heat energy of the water.

On this assumption, the heat of the liquid on the basis of 1 lb. of water for any boiling point may be determined as follows:

First: Note the boiling temperature, degrees F.

Second: Subtract 32° from result First.

Third: Multiply result Second by the specific heat of water (take as unity (1) for satisfactory practical results) and obtain the heat of the liquid in B.T.U.

Note: To obtain the heat of the liquid for any given quantity of water, multiply result Third by the total weight of the water in pounds.

Work Problem S-1-5

The latent heat of evaporation applied to water as defined in the first lesson of this course may be expressed in more general terms as follows: The latent heat of steam is the heat required to change one pound of water at the temperature of the boiling point into dry saturated steam at the same temperature.

Work Problem S-1-6

When 1 lb. of water in the liquid state at atmospheric pressure is changed to the gaseous at tne same pressure, its volume is increased many times.

Work Problem S-1-7

In changing the volume of a pound of water to a pound of steam at the boiling point of 212° F. (corresponding to atmospheric pressure) some of the heat is used in doing external work, while the balance is utilized in changing its state. About one-thirteenth (1/13th) of the latent heat of a pound of steam at a temperature of 212° F. is used in do-

ing external work. The balance is used in changing the physical state of the water. Latent heat thus becomes a most important factor in considering steam heating systems, for when steam condenses, it gives up the same amount of heat as was added to the water when converting it into steam and with condensation occurring in the radiators, the latent heat is that heat which is employed in warming the room.

Work Problem S-1-8

Contrary to an impression held by those who have never attempted to use a steam table, a long course of training is not a prerequisite to be able to use it for solving many seemingly difficult problems. The first step is to understand the headings given above each of the columns of figures that together compose the table.

Table S-1-1 represents a condensed steam table. Columns 1 and 2 contain figures that indicate pressures. The pressure at which the steam may be generated or used may be expressed in one of two ways—by gage pressure or by absolute pressure. Gage pressure represents the pressure above atmospheric pressure (unless there is a partial vacuum, when it is expressed as inches of mercury) while absolute pressure includes atmospheric pressure. Thus, the value 14.7 lbs. per square inch from Column 2 is equivalent to 0 lbs. per square inch from Column 1 and absolute pressure for any gage pressure may be found by adding 14.7 to the gage pressure.

Work Problem S-1-9

Water when heated in an open vessel will boil at a temperature of 212° F. when the pressure is atmospheric or 14.7 lbs. Thus steam, under atmospheric pressure, has a temperature of 212° F. as shown by Column 3.

Work Problem S-1-10

If the temperature of 1 lb. of water is raised from 32° F. to 212° F. in an open vessel, a definite number of heat units will have been put into the pound of water. Column 4, Heat of the Liquid, shows this quantity under various conditions of pressure. Thus, at 14.7 lbs. per square inch, temperature 212° F., the B.T.U. in the liquid (water) is 180 B.T.U.

When 1 lb. of water at a given pressure is converted into steam, a definite quantity of heat is required. This quantity of heat causes change in state without increase in temperature. It is called the Latent Heat of Evaporization. Its value depends upon the pressure under which the change of state occurs. Thus, for atmospheric pressure, the latent heat of evaporization by Column 5 is 970.4 B.T.U.

Work Problem S-1-13

One pound of water at 32° F., if converted into steam at a definite pressure, will contain a definite amount of heat which is indicated in Column 6 as Total Heat of the Steam. It consists of the heat of the liquid, added to the latent heat of evaporization, or the sum of Columns 4 and 5.

Work Problem S-1-14

A pound of steam, at different pressures, will have different volumes. Specific volume, Column 7, represents the volume in cubic feet that a pound of steam will occupy at a given pressure. Thus, at atmospheric pressure, every pound of steam generated, will have a volume of 26.79 cu. ft.

Work Problem S-1-15

TABLE S-1-1
PROPERTIES OF SATURATED STEAM
(CONDENSED MARKS AND DAVIS)

VACUUM INS. OF MERCURY OR LBS. GAGE	PRES. ABS. LBS. PER SQ. IN.	TEMP. DEG. F.	HEAT OF THE LIQUID	LATENT HEAT OF EVAP.	TOTAL HEAT OF THE STEAM	SP. VOL. CU. FT. PER LB.	SP. DEN. LBS PER CU. FT.
1	2	3	4	5	6	7	8
29.74	0.0886	32	0.00	1073.4	1073.4	3294	0.000304
29.67	0.1217	40	8.05	1068.9	1076.9	2438	0.000410
29.56	0.1780	50	18.08	1063.3	1081.4	1702	0.000587
29.40	0.2562	60	28.08	1057.8	1085.9	1208	0.000828
29.18	0.3626	70	38.06	1052.3	1090.3	871	0.001148
28.89	0.505	80	48.03	1046.7	1094.8	636.8	0.001570
28.50	0.696	90	58.00	1041.2	1099.2	469.3	0.002131
28.00	0.946	100	67.97	1035.6	1103.6	350.8	0.002851
27.88	1	101.83	69.8	1034.6	1104.4	333.0	0.00300
25.85	2	126.15	94.0	1021.0	1115.0	173.5	0.00576
23.81	3	141.52	109.4	1012.3	1121.6	118.5	0.00845
21.78	4	153.01	120.9	1005.7	1126.5	90.5	0.01107
19.74	5	162.28	130.1	1000.3	1130.5	73.33	0.01364
17.70	6	170.06	137.9	995.8	1133.7	61.89	0.01616
15.67	7	176.85	144.7	991.8	1136.5	53.56	0.01867
13.63	8	182.86	150.8	988.2	1139.0	47.27	0.02115
11.60	9	188.27	156.2	985.0	1141.1	42.36	0.02361
9.56	10	193.22	161.1	982.0	1143.1	38.38	0.02606
7.52	11	197.75	165.7	979.2	1144.9	35.10	0.02849
5.49	12	201.96	169.9	976.6	1146.5	32.36	0.03090
3.45	13	205.87	173.8	974.2	1148.0	30.03	0.03330
1.42	14	209.55	177.5	971.9	1149.4	28.02	0.03569
0.00	14.70	212.0	180.0	970.4	1150.4	26.79	0.03732
0.3	15	213.0	181.0	969.7	1150.7	26.27	0.03806
1.3	16	216.3	184.4	967.6	1152.0	24.79	0.04042
2.3	17	219.4	187.5	965.6	1153.1	23.38	0.04277
3.3	18	222.4	190.5	963.7	1154.2	22.16	0.04512
4.3	19	225.2	193.4	961.8	1155.2	21.07	0.04746
5.3	20	228.0	196.1	960.0	1156.2	20.08	0.04980
6.3	21	230.6	198.8	958.3	1157.1	19.18	0.05213
7.3	22	233.1	201.3	956.7	1158.0	18.37	0.05445
8.3	23	235.5	203.8	955.1	1158.8	17.62	0.05676
9.3	24	237.8	206.1	953.5	1159.6	16.93	0.05907
10.3	25	240.1	208.4	952.0	1160.4	16.30	0.0614
11.3	26	242.2	210.6	950.6	1161.2	15.72	0.0636
12.3	27	244.4	212.7	949.2	1161.9	15.18	0.0659
13.3	28	246.4	214.8	947.8	1162.6	14.67	0.0682
14.3	29	248.4	216.8	946.4	1163.2	14.19	0.0705
15.3	30	250.3	218.8	945.1	1163.9	13.74	0.0728
16.3	31	252.2	220.7	943.8	1164.5	13.32	0.0751
17.3	32	254.1	222.6	942.5	1165.1	12.93	0.0773
18.3	33	255.8	224.4	941.3	1165.7	12.57	0.0795
19.3	34	257.6	226.2	940.1	1166.3	12.22	0.0818
20.3	35	259.3	227.9	938.9	1166.8	11.89	0.0841
21.3	36	261.0	229.6	937.7	1167.3	11.58	0.0863
22.3	37	262.6	231.3	936.6	1167.8	11.29	0.0886

Condensed from "Steam Tables" of Marks and Davis, by permission of the publishers, Longmans, Green and Company.

Similarly, every cubic foot of steam will have a definite weight depending upon its pressure. Specific density therefore designates, weight (in pounds) per unit volume (cu. ft.) and by Column 8, the specific density, or weight of 1 cu. ft. of steam at atmospheric pressure is 0.03732 lbs.

Work Problem S-1-16

When steam and water or steam, water and air are mixed at different temperatures, and the problem of determining the final temperature and condition of the mixture is presented, the steam table must be called into play.

Since the steam in whole or in part, during the mixing process, experiences a change of state, three conditions must be considered: (a) all the steam may be condensed and the water therefrom cooled; (b) only condensation of all the steam may occur; (c) only part of the steam may be condensed.

The amount of heat given off by dry saturated steam for each of the three conditions may be determined as follows:

For condition (a):

First: Note the temperature of the steam corresponding to the pressure at which the steam is condensed.

Second: Note the temperature of the water to which the condensed steam is lowered.

Third: Subtract result Second from result First and note the temperature difference.

Fourth: Multiply result Third by the correct value for the specific heat of water.

Fifth: Note the latent heat of steam corresponding to the temperature under First.

Sixth: Add results Fourth and Fifth and obtain a value for the amount of heat, given off per pound of steam.

Work Problem S-1-17

For condition (b):

The heat given off will be equal to the latent heat of evaporization for the given pressure and the temperature of the mixture will be that corresponding to the pressure.

Work Problem S-1-18

For condition (c):

First: Note the latent heat of steam for the pressure at which condensation occurs.

Second: Multiply result First by the proportionate amount of steam condensed expressed as a decimal and obtain a value for the amount of heat given off per pound.

Work Problem S-1-19

The above three examples relate only to condensation of steam. When mixtures are encountered, the problem is somewhat different. The heat available for use will not be as great as the total heat given up by the steam.

To find the final temperature and condition of a mixture of ice, water and steam, when mixture takes place at atmospheric pressure, proceed as follows:

First: Multiply temperature rise of ice by specific heat of ice and obtain the B.T.U. required to raise 1 lb. of ice to its melting point.

Second: Multiply result First by weight of ice in the mixture.

Third: Multiply weight of ice by Latent Heat of Fusion for ice and obtain B.T.U. required to change the ice to water at 32° F.

Fourth: Add results Second and Third and obtain total B.T.U. necessary to change all ice at its original temperature to water at 32° F.

Fifth: Subtract 32° F. from the temperature of the water of the mixture.

Sixth: Multiply result Fifth by original weight of water and obtain a value for heat given up by the original water in lowering its temperature to 32° F.

Seventh: Multiply the total heat in 1 lb. of steam at atmospheric pressure (from steam table) by the pounds of steam in the mixture and obtain total heat available from the steam.

Eighth: Add results Sixth and Seventh and obtain total heat given up by water and steam if lowered to 32° F.

Ninth: Subtract result Fourth from result Eighth and obtain the net heat available for use.

Tenth: Divide result Ninth by total combined weight of ice, water, and steam, and obtain the number of degrees that the net available heat will raise the mixture.

Eleventh: To result Tenth, add 32° F. and obtain the final temperature of the mixture.

Twelfth: If result Eleventh is lower than the temperature of the boiling point corresponding to the pressure, at which the mixture took place, this indicates that all the steam was condensed.

Work Problem S-1-20

To find the final temperature and condition of a mixture of ice, water, air and steam, when mixture takes place at a pressure greater than atmospheric pressure.

First: Multiply temperature rise of ice by specific heat of ice and obtain the B.T.U. required to raise 1 lb. of ice to its melting point.

Second: Multiply result First by weight of ice in the mixture.

Third: Multiply weight of ice by latent heat of fusion for ice.

Fourth: Add results Second and Third and obtain total B.T.U. necessary to change all the ice at its original temperature to water at 32° F.

Fifth: Subtract 32° F. from the temperature of the water of the mixture and multiply remainder by original weight of water of the mixture and obtain a value for heat given up by water in lowering its temperature to 32° F.

Sixth: Subtract 32° F. from the temperature of the air of the mixture and multiply remainder by specific heat of air.

Seventh: Multiply result Sixth by weight of air of the mixture and obtain a value for heat given up by air in lowering its temperature to 32° F.

Eighth: Multiply total heat in 1 lb. of dry saturated steam at the stated steam pressure by the pounds of steam in the mixture and obtain a value for the total heat available from the steam.

Note: If steam is not dry but contains a percentage of moisture, the Eighth step should be modified by using, in place of the total heat in 1 lb. of dry steam, the following: The product of the latent heat by the per cent of dryness increased by the heat of the liquid as for a 3% moisture and steam at 20 lbs. absolute pressure, 196.1 + 0.97 × 960.0, and this sum multiplied by the pounds of steam in the mixture.

Ninth: Add results Fifth, Seventh and Eighth and obtain the total heat available from air, water and steam.

Tenth: Subtract result Fourth from result Ninth and obtain net heat available.

Eleventh: Subtract 32° F. from the temperature of the steam corresponding to the pressure and multiply remainder by the specific heat of air.

Twelfth: Multiply result Eleventh by weight of air in the mixture and obtain the heat required to raise the air to the temperature corresponding to the steam pressure.

Thirteenth: Subtract result Twelfth from result Tenth and get the heat available to raise the temperature of the water.

Fourteenth: Multiply the heat in the liquid corresponding to the steam pressure from steam table by the combined weight of steam, ice and water and obtain the heat required to raise all the water of the mixture to the temperature corresponding to the steam pressure.

Fifteenth: Subtract result Fourteenth from result Thirteenth and obtain the heat available to evaporate water.

Sixteenth: Divide result Fifteenth by the latent heat of steam corresponding to the temperature and obtain the pounds of dry steam remaining uncondensed.

Seventeenth: Subtract result Sixteenth from the total weight of water in the mixture and obtain the net pounds of water in the final mixture.

Eighteenth: Record the amount of each substance in the mixture and its final temperature.

Work Problem S-1-21, S-1-22

PART S.

STEAM HEATING SYSTEMS

LESSON 2.

Steam Systems Classified

STEAM HEATING SYSTEMS.

Heating with steam is accomplished as follows:— (1) Water is boiled and changed to steam, (2) the steam passes through a system of piping to the radiator, (3) air that entered with the steam is removed from the radiator, (4) the steam condenses within the radiator, giving up to the radiator the latent heat of evaporation, (5) the condensed steam flows from the radiator through the piping system back to the boiler to be re-evaporated.

The several types of steam-heating systems differ from one another in the manner in which the operations enumerated above are performed.

Work Problem S-2-1

In general, direct steamheating systems may be divided into two classes (1) gravity circulating systems, (2) mechanical circulating systems. The difference lies essentially in the manner in which the water of condensation from the radiating surfaces is returned to the boiler for re-evaporation.

In the first class, as the name implies, the water is returned to the boiler below the water line by gravity. Traps may or may not be used. The flow is due entirely to the static head existing in the returns, the system being a closed circuit. In this system, the same steam pressure exists in the boiler, mains and radiators except for slight reduction due to friction pressure losses occurring in the pipes that conduct the steam to the radiating surfaces.

In the second class, as the name implies, mechanical means is employed for returning the water to a receiver or feed-water heater from which it is forced into the boiler by a pump or by return traps or by both. The system therefore does not constitute a closed circuit and the pressure in the boiler may be much higher than in the steam supply pipes or in the radiators. The receiver is usually vented to the atmosphere. In the case of vacuum systems, an additional pump is connected directly to the returns and discharges the condensation into the receiver. These systems are not covered in this course.

CLASSIFICATION OF GRAVITY STEAM SYSTEMS

Gravity steam heating systems may be considered as of eight types, namely, (1) Strictly one-pipe system (sometimes called a camel-back system), (2) One-pipe circuit system with wet or dry return, (3) One-pipe relief system with wet or dry return, (4) One-pipe overhead system, (5) Two-pipe dry-return system, (6) Two-pipe wet-return system, (7) Two-pipe low-pressure gravity vapor system, with or without radiator return traps, (8) Two-pipe steam system with return traps.

The general arrangements of the piping for each of the types enumerated are shown in Fig. S-2-1 to S-2-8 inclusive, each being taken up in detail in subsequent lessons and design problems assigned in connection therewith.

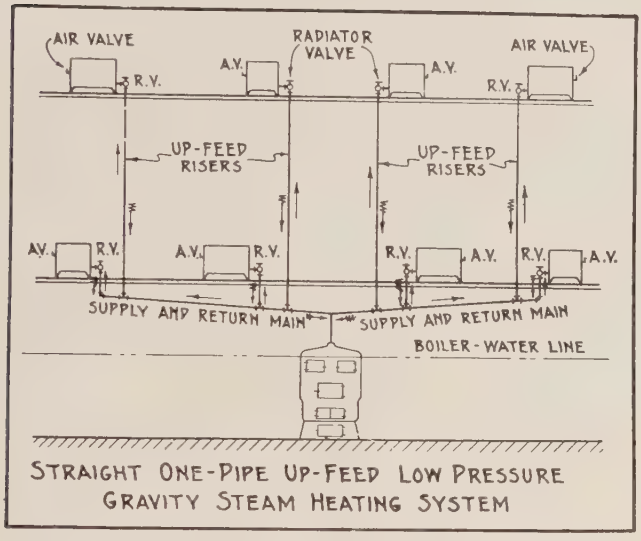


Fig. S-2-1

STRICTLY ONE-PIPE STEAM SYSTEM

Fig. S-2-1 shows the simplest form of a one-pipe steam heating system. With this arrangement of piping, steam leaves the boiler, and passes into the steam mains which may lead in one or several directions, and are graded up from the boiler. Risers are connected to the steam mains, and through these, the steam passes to the radiators, entering at the bottom of one of the end sections. The steam flowing through the mains and risers drives the air in the pipes ahead of it into the radiators from which it is exhausted through one of several types of air valves connected on the end radiator section opposite the supply connection.

With this arrangement, the water of condensation in the radiator drains down the supply riser into the mains and finally flows back into the boiler.

The direction of the flow of the condensation in this system is therefore opposite to that of the steam. In the risers this is not particularly objectionable, but in the mains, interference is likely to prove an annoyance. Therefore, it is necessary with this type of system to design the mains so that the steam will flow therein at a very low velocity.

If this provision is not observed, and the flow of steam interferes with the flow of water in an opposite direction, the steam will pick up quantities of water, drive it to the end of the main, and cause "water hammer," a loud intermittent cracking noise, particularly objectionable when steam is first turned into a cold system when the rate of condensation is much higher than after the system has warmed up.

Work Problem S-2-2

ONE-PIPE CIRCUIT SYSTEM

(Wet or Dry Return)

Fig. S-2-2 illustrates this type of system which is the most common form of a one-pipe steam system. It has much to commend it as compared to the strictly one-pipe system shown as Fig. S-2-1.

In this system the steam main leaving the boiler is graded downwards from the boiler. Risers supply the radiators, as in the previously-described system, as well as carry the condensation back to the main. In the main, however, the condensation flows in the same direction as the steam which constitutes a distinct point in favor of this system. The steam main extends around the basement so as to supply all radiators and at its end or ends, a drop is made to a height such that the water will flow back to the boiler.

This return line may be run as a wet return (shown on the right of Fig. S-2-2) or as a dry return (shown on the left of Fig. S-2-2. It should be noted that the distinction depends upon the location of the return line with respect to the boiler

water-line. If lower than the water-line, it is called a wet return, if higher than the water-line until near the boiler, it is called a dry return.

Work Problem S-2-3

ONE-PIPE RELIEF SYSTEM

Fig. S-2-3 illustrates a one-pipe relief steam heating system, sometimes erroneously referred to as a two-pipe system. It takes its names from the fact that the steam main is relieved of condensation at various points; in fact, whenever a riser is taken from the main and because there is a direct connection between the return line and radiator, thus permitting the condensation from the radiator to be carried immediately to the return line, instead of requiring it to flow through a part of the steam main to its end before dropping into the return line. The return is run as a wet return. The steam main is placed close to the basement ceiling, and conserves head room. It properly falls in the one-pipe class since there is but one connection to the radiator.

Work Problem S-2-4

ONE-PIPE OVERHEAD SYSTEM

Fig. S-2-4 shows a one-pipe overhead steam system, in which the steam main is carried direct to

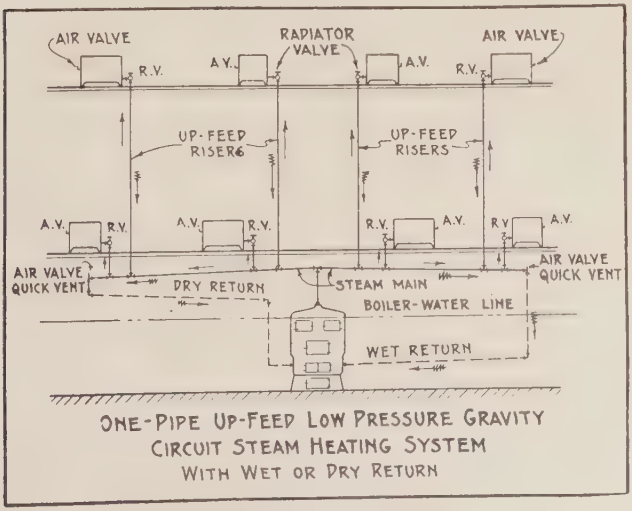


Fig. S-2-2

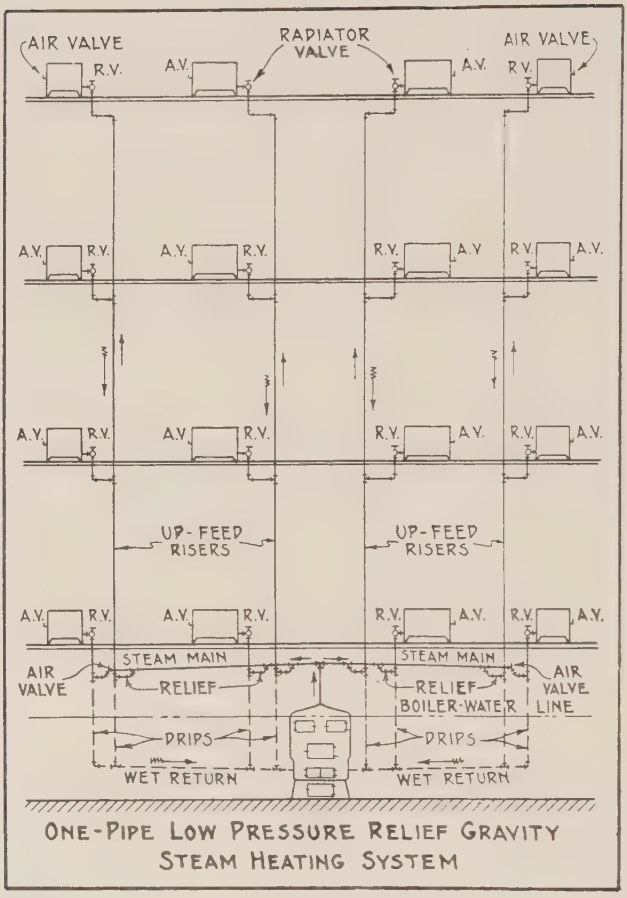


Fig. S-2-3

the attic before any radiators are supplied. It is then run around the attic and drop risers are connected thereto at such points as will accommodate the radiators on the several floors. These drop risers extend to the return line in the basement, with branches taken off for supplying the radiators. The return may be installed as a wet or dry return. In this system all steam and water within the system flow in the same direction. It is generally used for buildings having more than two stories where attic space is available. This system may be installed also as an up-feed two-pipe system, a description of which follows.

Work Problem S-2-5

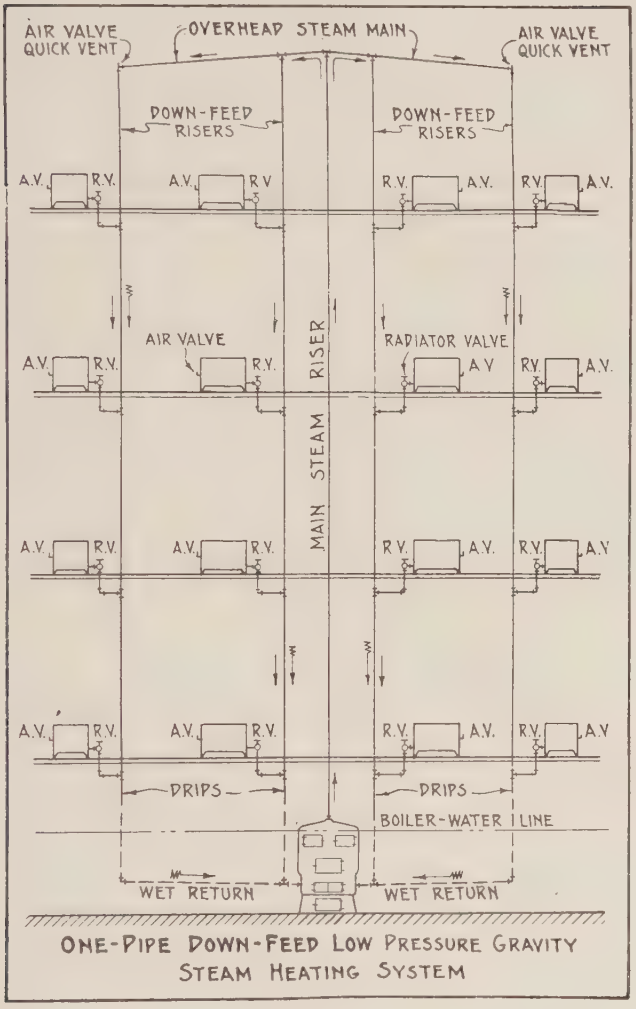


Fig. S-2-4

TWO-PIPE UP-FEED DRY RETURN SYSTEM

Fig. S-2-5 shows a two-pipe dry return steam system. In a system with a dry return, the return main being above the water-line in the boiler, it is filled largely with steam. The supply connections are made in much the same manner as for one-pipe work. In addition, a return connection is made from the other side of the radiator with the

return main. The condensation and steam thus have separate lines, and the steam has a free passage from the supply main, through the radiator, and into the return. The return thus will contain steam under a pressure but slightly less than exists in the supply main. The difference is due to the resistance caused by passage through radiator and piping. The end of each supply main is dripped into the return through a 4 or 5-ft. water seal. The water in this seal prevents the full steam pressure in the main from entering the return. It should be noted that in this type of two-pipe steam system, two valves are used on each radiator, one on the supply and one on the return. A feature of the dry return, sometimes considered objectionable, is the tendency at times, for steam to enter the radiator through the return valve, especially if, when starting up, this valve happens to be opened before the supply valve. Air may then be trapped in the radiator and interfere with proper heating of the radiator.

Work Problem S-2-6

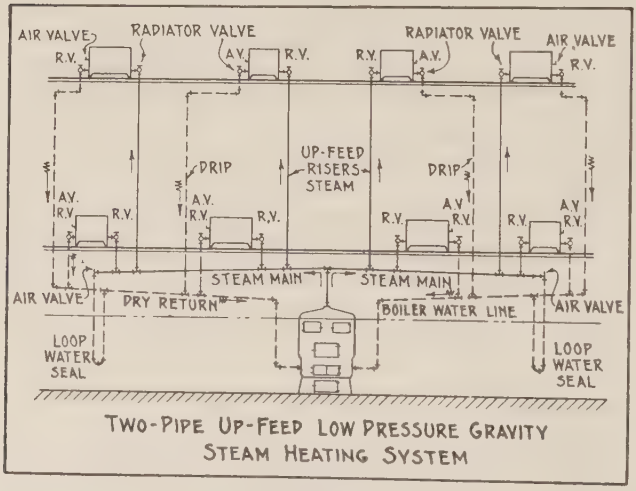


Fig. S-2-5

TWO-PIPE UP-FEED WET RETURN SYSTEM

Fig. S-2-6 shows the arrangement of piping of a two-pipe up-feed wet return system. With this method of piping there is no possibility of steam

entering the radiator through the return since separate connections are made to the return for each radiator, and each of these connections is water-sealed, as indicated by the heavy lines in Fig. S-2-6. The water in each of these return risers will stand a little higher than the water-line in the boiler. This difference in elevation is due to friction losses in piping and radiators, and consequent reduction or loss in pressure so that the water in the riser farthest from the boiler will rise high enough to balance the pressure drop between the two points. As the boiler is approached, this pressure drop will become less. Consequently, the height of water in the return risers near the boiler for radiators on the same floor will more nearly equal that of the water in the boiler. Therefore, sizes of pipe must be such as to avoid an excessive pressure drop. All radiators should be set at least 2 ft. above the water-line in the boiler. The wet return system is usually quieter than the dry return system since all condensation drops directly into the return, and does not travel in a horizontal direction and make a 90° turn at the end of the main.

Work Problem S-2-7

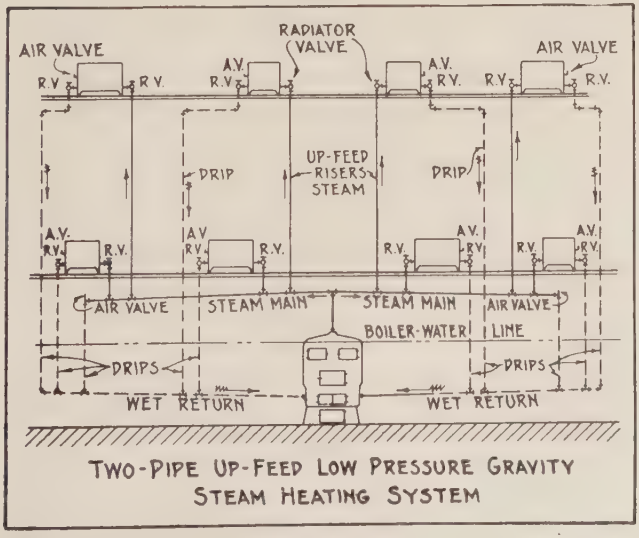


Fig. S-2-6

In general, two-pipe systems of the types shown in Fig. S-2-5 and S-2-6 employing two radiator valves are now seldom installed, having been superseded largely by the so-called vapor system illustrated in Fig. S-2-7.

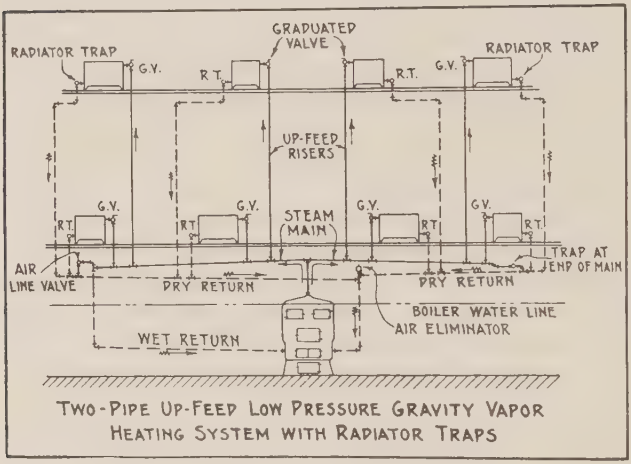


Fig. S-2-7

TWO-PIPE LOW-PRESSURE GRAVITY VAPOR SYSTEM WITH OR WITHOUT RADIATOR RETURN TRAPS

Fig. S-2-7 shows an arrangement of piping for a gravity vapor system. As explained in the preceding lesson, vapor is steam at a pressure equal to or slightly above atmospheric pressure. Consequently a vapor system is a very low-pressure steam system operating at pressures but slightly above atmospheric pressure. Vapor systems have features that are essentially different from steam heating systems operating at a pressure from 1 to 5 lbs. gage.

Water-type radiators having top supply and bottom return are used. A supply valve of the graduated type which permits control of the quantity of steam admitted into the radiator is employed. No steam is permitted to enter the return lines which are open to the atmosphere or are maintained under a pressure slightly below atmospheric.

The returns from the radiators must connect with the dry return main. The end of the steam main may be dripped to a wet return but must be vented into the dry return.

Work Problem S-2-8

TWO-PIPE STEAM SYSTEM WITH RETURN TRAPS

Fig. S-2-8 shows a two-pipe steam system with return trap. The characteristic feature of this system is the trap, the function of which is to separate the air and water discharged into the dry return piping, to release the air and to return the water to the boiler, regardless of the pressure carried in the boiler or in the system provided it is within the maximum limit of the trap operating pressure, usually not exceeding 10 lbs. per square inch gage. Special radiator supply valves and

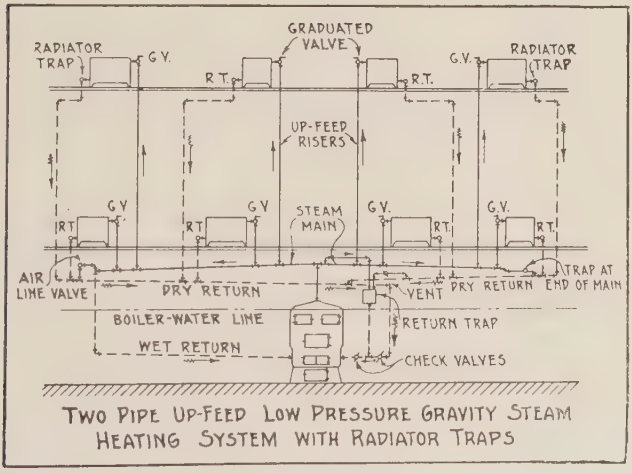


Fig. S-2-8

radiator traps are required as indicated in the figure. No steam is permitted in the return mains.

Wet returns are usually connected direct to the boiler, and, therefore, are under the same pressure as that maintained in the boiler. Steam lines connecting the wet return must be vented to the dry return through air line valves. The dry returns are either open to the atmosphere or, by means of

special vents, seal the returns automatically so as to maintain a vacuum within the system. Due to the large difference in pressure within the boiler and the dry return it is necessary to use special equipment to return to the boiler the condensation collecting in the dry returns. This is often done by using a direct return trap, which forces the condensation into the boiler by means of the steam pressure within the boiler. This will be explained more fully when this system is taken up in detail.

Work Problem S-2-9

FLOW OF STEAM IN PIPES

Before taking up the different systems of steam heating in detail and applying design problems for each, it is important that the principles governing the flow of steam in pipes be understood, at least, in a general way.

In order that a fluid may flow through a pipe, it is necessary that the fluid be under pressure so that it will move in spite of the friction caused by the inner surface of the pipe. Laws governing the friction of fluids in pipes have been established by experiment. They may be expressed as follows:

(a) The total frictional resistance to flow is independent of the absolute pressure of the fluid against the walls of the pipe. Thus, the frictional resistance is the same, regardless as to whether the pressure is 10 lbs. or 100 lbs. per square inch.

(b) The frictional resistance varies directly as the area of contact between the fluid and the pipe wall. The area of contact depends upon two things, the internal diameter of the pipe and the length of the pipe.

Fig. S-2-9 represents a section of pipe through which steam may be assumed to be flowing. The length denoted by L may represent any distance along a straight section of pipe. If this distance be doubled, the diameter D remaining unchanged, the frictional resistance to steam flow will be doubled or, in other words, frictional resistance for a pipe of given diameter will increase in the same proportion as the length increases.

If the diameter D be doubled and length L remain unchanged, the frictional resistance will be altered in a similar manner, but since the area of a pipe increases faster than its circumference for

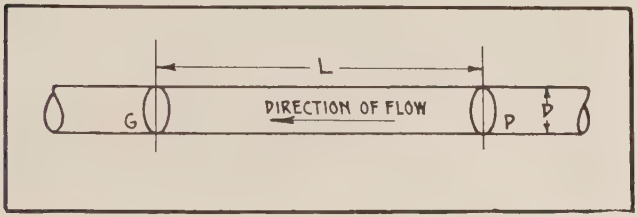


Fig. S-2-9. Basic Relation of Diameter and Length of Pipe to Steam Flow.

increase in diameter, a greater volume of steam will flow in a larger pipe and the net loss will be reduced.

Work Problem S-2-10

(c) The frictional resistance varies nearly as the square of the velocity. Thus, for a given frictional resistance, if steam is flowing in a pipe at a velocity of 10 ft. per second, by increasing this velocity to 40 ft. per second, with the other factors remaining the same, the resistance will be increased 16 times, obtained as follows:

$$40^2 \div 10^2 = 16$$

Work Problem S-2-11

(d) The frictional resistance varies directly as the density of the fluid. Thus the denser or the heavier the fluid, the greater will be the resistance. So, if the pressure of steam weighing 0.04976 lbs. per cubic foot at 5 lbs. gage is raised to 55 lbs. gage, at which pressure its weight will be 0.1609 lbs. per cubic foot, the frictional resistance will be increased as many times as the weight or density was increased. In this case it is 0.1609 divided by $0.04976 = 3.23$ times.

Work Problem S-2-12

The effect of frictional resistance is to cause a reduction in the pressure between different points in the pipe line. If, for Fig. S-2-9, the static pressure be measured at sections P and G, it will differ at the two points, due to the frictional resistance of the pipe. The pressure drop between sections P and G will be equal to the difference between the static pressures at the respective points. It is customary in practice to fix a definite allowable pressure-drop between points in a steam pipe line and then to determine the size of pipe necessary to permit the required amount of steam to pass in a given time; or the problem may present itself as follows:

To determine the drop in pressure in a pipe line of a given size and length when steam at a given velocity under a certain pressure is flowing therein; or the problem may involve these conditions but be expressed in a still different manner. Examples, solutions and problems follow that cover the usual forms in which they are met.

The flow of steam in pipes has been studied by different investigators, and formulae involving theoretical considerations, modified by coefficients obtained from experiments, have been presented.

The following factors are involved in problems relating to the flow of steam in pipes:—the weight of steam flowing, expressed in pounds per minute or in pounds per hour; the length of the pipe, usually expressed in feet; the initial pressure of the steam, in pounds per square inch; the final pressure of the steam, in pounds per square inch; the drop in pressure between the initial and final supply points; the velocity of flow of the steam, in feet per second or feet per minute; and the diameter of the pipe, expressed usually in inches.

Formulae, charts, and tables are useful in solving problems involving the flow of steam. An example of each will be presented in turn.

FORMULA FOR STEAM FLOW

A formula recognized as authoritative is known as Babcock's (G. H. Babcock) and involves all of the factors enumerated above, modified by a coefficient determined experimentally. The use of a

formula in calculating flow of steam is, at its best, laborious, but it is well, where time will permit, and especially when studying the subject, to check results, obtained otherwise, by the formula.

APPLICATION OF BABCOCK'S FORMULA

To Determine the Quantity of Steam Flowing through a Pipe under Definite Conditions—PROBLEM—How many pounds of steam will be delivered per minute through 225 ft. of 3-in. pipe if the initial pressure is 10.3 lbs. gage and the final pressure is 8.3 lbs. gage?

SOLUTION:

First: Subtract the final pressure from the initial pressure and get the pressure-drop in pounds per square inch.

$$10.3 - 8.3 = 2 \text{ lb. pressure drop}$$

Second: Add 14.7 lbs. to the initial pressure and get the initial pressure in pounds per inch, absolute.

$10.3 + 14.7 = 25$ lbs. per square inch, absolute.

Third: Add 14.7 lbs. to the final pressure and get the final pressure in pounds per square inch, absolute.

$8.3 + 14.7 = 23$ lbs. per square inch, absolute.

Fourth: Determine the mean absolute pressure by adding one-half the difference between result SECOND and THIRD to the final pressure, absolute.

$$(25 - 23) \div 2 = 1 \text{ lb.}$$

23 lbs. + 1 lb. = 24 lbs. as mean pressure, absolute.

Fifth: Note the weight of 1 cu. ft. of steam at mean pressure, absolute. See steam table for 24 lbs. absolute pressure, 1 cu. ft. steam weighs 0.0590 lbs.

Sixth: Note the actual inside diameter of the pipe in inches. 3-in. pipe, 3.068 in. diam.

Raise this quantity to the fifth power.

$3.068 \times 3.068 \times 3.068 \times 3.068 \times 3.068 = 271.8$

Seventh: Multiply result FIRST by result FIFTH by result SIXTH.

$$2 \times 0.0590 \times 271.8 = 32.$$

Eighth: Add 3.6 to the inside diameter of pipe as noted under SIXTH. 3.6 plus 3.068 = 6.668.

Ninth: Divide result EIGHTH by inside diameter of pipe.

$$6.668 \div 3.068 = 2.18$$

Tenth: Multiply result NINTH by length of pipe in feet.

$$2.18 \times 225 = 490.$$

Eleventh: Divide result SEVENTH by result TENTH and take the square root of the quotient.

$$32 \div 490 = 0.0653$$

$$\text{Square root of } 0.0653 = 0.256$$

Twelfth: Multiply result ELEVENTH by 87 and obtain the pounds of steam per minute.

$$0.256 \times 87 = 22 \text{ lbs. per minute.}$$

Work Problems S-2-13, S-2-14

To Determine the Pressure Drop when a Given Quantity of Steam is Flowing through a Given Pipe.

PROBLEM:

Determine the drop in pressure through 225 ft. of 3-in pipe when 25 lbs. of steam is flowing per minute. Initial pressure equals 10.3 lbs. gage.

First: Multiply the value for quantity of steam in pounds per minute by itself.

$$25 \times 25 = 625.$$

Second: Multiply result FIRST by length of pipe in feet. $625 \times 225 = 141{,}000$.

Third: Add 3.6 to the inside diameter of pipe.

$$3.6 + 3.068 = 6.668$$

Fourth: Divide result THIRD by the inside diameter of pipe.

$$6.668 \div 3.068 = 2.18$$

Fifth Multiply result SECOND by result FOURTH.

$$141{,}000 \times 2.18 = 307{,}000.$$

Sixth: Raise the inside diameter of the pipe to the fifth power.

$$3.068 \times 3.068 \times 3.068 \times 3.068 \times 3.068 = 271.8$$

Seventh: Multiply result SIXTH by the weight of 1 cu. ft. of steam at initial absolute pressure. This must be used since average pressure cannot be obtained. For 25 lbs., absolute, weight of 1 cu. ft. = 0.0613.

$$271.8 \times 0.0613 = 16.6$$

Eighth: Divide result FIFTH by result SEVENTH.

$$307{,}000 \div 16.6 = 18{,}500$$

Ninth: Multiply result EIGHTH by 0.0001321 and obtain pressure drop in pounds.

$$18{,}500 \times 0.0001321 = 2.44 \text{ lbs.}$$

Work Problem S-2-15, S-2-16

CHART FOR FLOW OF STEAM IN PIPES.

The chart Fig. S-2-10, prepared originally by Prof. H. V. Carpenter, shows the relation between size of pipe, average pressure, drop in pressure, and weight of steam passing in pounds per minute.

APPLICATION OF CHART.

(a) To determine the weight of steam in pounds per minute that will be delivered through a 4-inch pipe at an average pressure of 60 lbs. absolute, through 325 ft. of pipe with a pressure drop of 8 lbs.

SOLUTION:

Drop per 100 ft. = $8 \div 3.25 = 2.46$ lbs., say 2.5. Follow up the 2.5 point on bottom to intersect the 4-in. line from the left; turn down and running parallel to the inclined lines, intersect the 60-lb. point line from the top; turn horizontally to the right, follow over and read about 120 lbs. of steam per minute.

Work Problem S-2-17.

(b) To determine the average absolute pressure required in order that a 6-inch pipe will deliver 350 lbs. of steam per minute through 225 ft., with an allowable pressure drop of 5 lbs.

SOLUTION:

Drop per 100 ft. $= 5 \div 2.25 = 2.22$ lbs., say 2.25. Follow up the 2.25 line from the bottom to intersect the 6-in. line from the left; turn and continue upwards parallel to the diagonal lines until a horizontal line from the 350 point on the right is intersected. This point lies between the 60 and 80 lines from the top. Estimate this at about 70 lbs. absolute as required.

Work Problem S-2-18

(c) To determine the drop in pressure when a 3-in. pipe is delivering 50 lbs. of steam per minute through 75 ft. under an average absolute pressure of 20 lbs.

SOLUTION:

Follow over horizontally from the 50 point on the right to intersect the 20 line from the top; follow down diagonally and intersect the 3-in. line from the left; follow vertically down from this last point and read a pressure drop of 6.3 lbs. in 100 ft. For 75-ft. length, multiply 6.3 by 0.75 and read 4.73 lbs. drop.

Work Problem S-2-19

(d) To determine the size of pipe required to deliver 700 lbs. of steam per minute through 75 ft. of pipe under an average absolute pressure of 30 lbs. per square inch, with a total pressure drop of 3.5 lbs.

SOLUTION:

Drop for 100 ft.; $3.5 \div 0.75 = 4.57$ lbs., say 4.5. Erect a perpendicular line from 4.5 line at the bottom; follow over horizontally from the 700-lb. point on right to meet 30 lbs. line from top; follow diagonally and intersect the vertical line up from 4.5. This intersects slightly below the 8-in. line from the left so that an 8-in. pipe is required.

Work Problem S-2-20

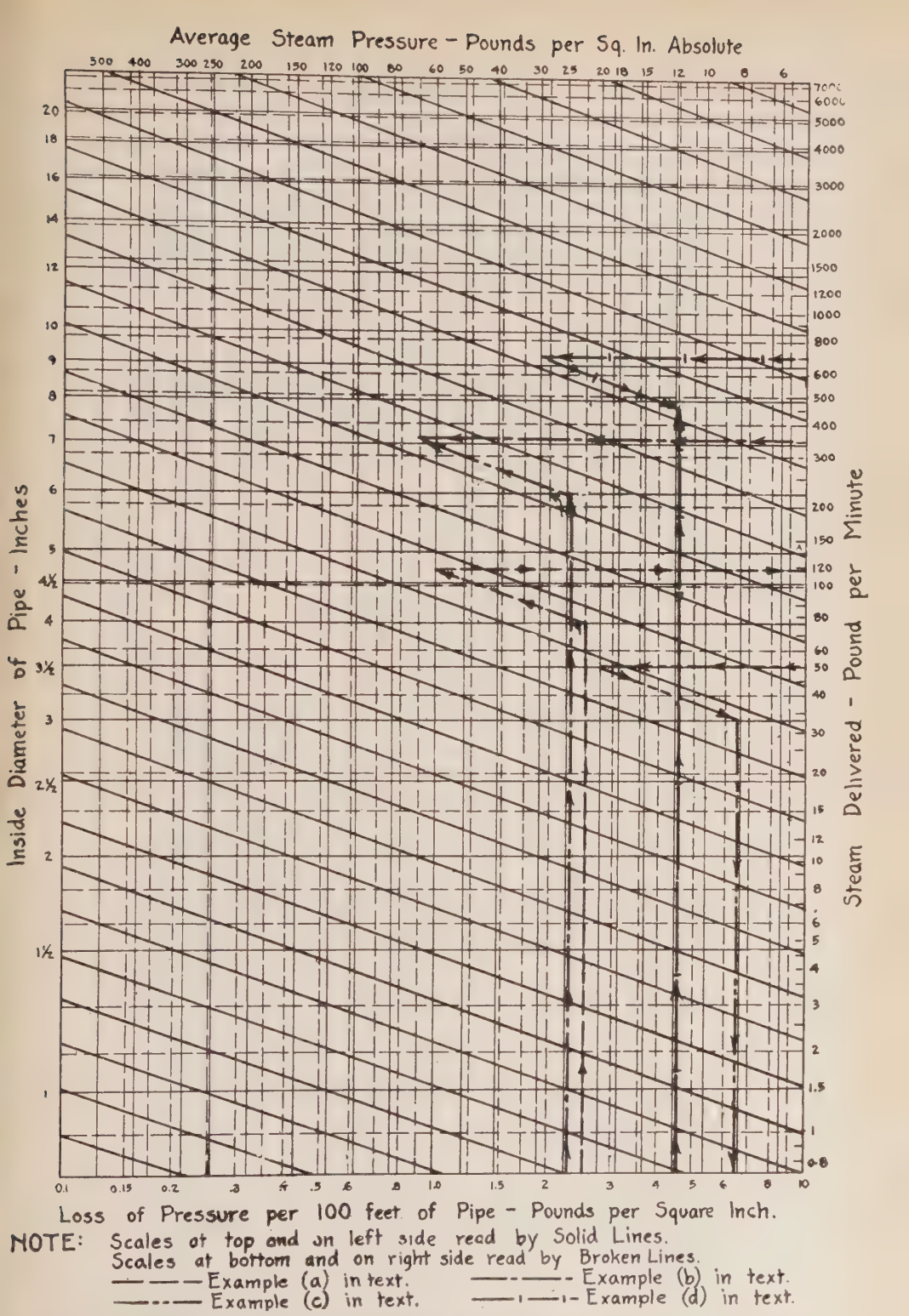

Average Steam Pressure – Pounds per Sq. In. Absolute
500 400 300 250 200 150 120 100 80 60 50 40 30 25 20 18 15 12 10 8 6
Inside Diameter of Pipe – Inches
20 18 16 14 12 10 9 8 7 6 5 4½ 4 3½ 3 2½ 2 1½ 1
Steam Delivered – Pound per Minute
7000 6000 5000 4000 3000 2000 1500 1200 1000 800 600 500 400 300 200 150 120 100 80 60 50 40 30 20 15 12 10 8 6 5 4 3 2 1.5 1 0.8
0.1 0.15 0.2 .3 .4 .5 .6 .8 1.0 1.5 2 3 4 5 6 8 10
Loss of Pressure per 100 feet of Pipe – Pounds per Square Inch.
NOTE: Scales at top and on left side read by Solid Lines.
Scales at bottom and on right side read by Broken Lines.
——— Example (a) in text.
——- ——- Example (b) in text.
——- - - Example (c) in text.
——-·-·- Example (d) in text.

Fig. S-2-10—"Chart for Determining Factors Affecting the Flow of Steam in Pipes."

TABLE FOR FLOW OF STEAM

One of the most convenient tables ever presented for this purpose was prepared by R. V. Frost for the American Society of Heating and Ventilating Engineers *Guide,* and is herewith included as Table S-2-1. Results are obtained from a formula differing but slightly from those as calculated by Babcock's formula.

This table consists of four columns marked respectively Columns 1, 2, 3, and 4. By the proper use of the values given in each column, the quantity of steam flowing or any one of the various quantities may be determined by simple multiplication or division when four of them are known or assumed.

TABLE S-2-1
FLOW OF STEAM IN PIPES
FACTORS

PRESS. LOSS OZ.	COL. 1 FACTOR	PIPE DIAMETER INSIDE	COL. 2 FACTOR	STEAM PRESS. GAGE	COL. 3 FACTOR	PIPE LENGTH FEET	COL. 4 FACTOR
1	2.175	1	0.522	0.0	0.193	20	2.240
2	3.076	1¼	1.177	0.3	0.195	40	1.580
3	3.767	1½	1.828	1.3	0.201	60	1.290
4	4.350	2	3.709	2.3	0.207	80	1.120
5	4.863	2½	6.109	5.3	0.223	100	1.000
6	5.328	3	11.183	10.3	0.248	120	0.912
7	5.754	3½	16.705	15.3	0.270	140	0.841
8	6.152	4	23.630	20.3	0.290	160	0.793
10	6.878	4½	32.098	30.3	0.326	180	0.741
12	7.532	5	43.719	40.3	0.358	200	0.710
14	8.138	6	69.718	50.3	0.388	250	0.632

ADAPTED FROM A.S.H.V.E. GUIDE '24-'25

Since water in low-pressure steam lines, condensation in covered pipe and roughness in commercial pipe will cause a reduction in steam flow as calculated by the formula, the value as obtained by using Table S-2-1 should be reduced 20%. The table may be used as follows:

To find the quantity of steam that will pass through a pipe of known diameter and length when the gage pressure and pressure loss through the pipe are known:

RULE: Multiply the quantities as taken from each column opposite the proper value by one another in turn and take 80% of the final product to obtain the quantity of steam in pounds per minute; multiply by 60 to express it in pounds per hour.

PROBLEM:

Determine the quantity of steam flowing through a 2½-in. pipe 80 ft. long when the gage pressure is 5.3 lbs. and the pressure loss is 1 oz.

SOLUTION:

Col. 1 × Col. 2 × Col. 3 × Col. 4 × 60 × 0.80 = lbs. of steam per hour or

2.175 × 6.109 × 0.223 × 1.120 × 60 × 0.80 = 159.31

Work Problem S-2-21

To find the size of pipe required to deliver a given quantity of steam a known distance from the boiler when the gage pressure and pressure drop are known or assumed.

RULE: Divide the quantity of steam in pounds per hour by the product of values from Col. 1 × Col. 3 × Col. 4 × 60 × 0.80.

Work Problem S-2-22

To find the boiler pressure needed to deliver at a required pressure a given quantity of steam through a pipe of known size and length.

RULE: Divide the quantity of steam in pounds per hour by the product of values from Col. 1 × Col. 2 × Col. 4 × 60 × 0.80.

Work Problem S-2-23

To find the pressure at which a given quantity of steam will be delivered through a pipe of known diameter and length for a given pressure at the boiler.

RULE: Divide the quantity of steam in pounds per hour by the product of values from Col. 2 × Col. 3 × Col. 4 × 60 × 0.80.

Work Problem S-2-24

PART S.

STEAM HEATING SYSTEMS

LESSON 3.

Steam Pipe Sizes

STEAM HEATING SYSTEMS.

In the preceding discussion and problems relating to the flow of steam through pipes, only straight lengths of pipe were considered. It is absolutely essential, when solving problems involving the flow of steam in pipes, in place of using the length as measured, that the equivalent length be used.

EFFECT OF PIPE FITTINGS, VALVES, ETC., UPON STEAM FLOW

Pipe fittings and valves in pipe lines introduce frictional resistance in excess of that for the same length of straight pipe. This additional resistance

must be taken into account when establishing the length factor for steam-flow computations and when so considered in conjunction with the measured length, the equivalent length of run is obtained.

If allowance is not made for the effect of ells, tees, and valves, the pressure drop may be so much greater than for the same length of run without fittings that an otherwise correctly designed steam system might fail to function properly.

In making allowance for tees in the line, no additional length need be included where the flow is directly through the tee. Where the length of run involves a flow through the side outlet, the proper equivalent length from Table S-3-1 should be included.

Work Problem S-3-1

While it is obviously impossible to present equivalent length of pipe for valves and other fittings that would be correct for all valves or fittings of the same size, since patterns of different manufacturers differ, yet a table of mean equivalent lengths may be used with satisfactory results.

TABLE S-3-1
EQUIVALENT LENGTH TO BE ADDED TO PIPING LENGTH FOR VARIOUS FITTINGS

Size of Pipe	Standard Elbow	Side Outlet Tee	Gate Valve	Globe Valve	Angle Valve
	Length in Feet to be Added				
2	5	16	2	18	9
2 1/2	7	20	3	25	12
3	10	26	3	33	16
3 1/2	12	31	4	39	19
4	14	35	5	45	22
5	18	44	7	57	28
6	22	50	9	70	32

Table S-3-1 contains lengths of pipe in feet that should be added to the measured length of a run to obtain equivalent length. It is applied as follows for pipe run A of Fig. S-3-1 for a pipe diameter of 2½in.

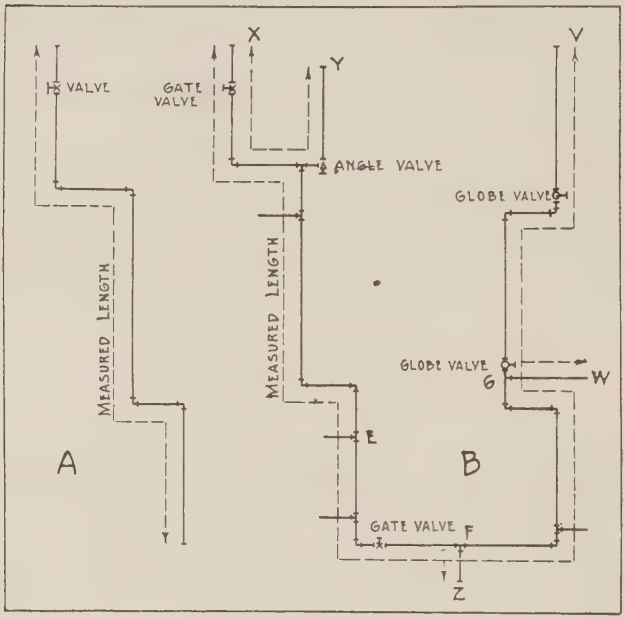


Fig. S-3-1 Pipe Runs Used in Calculation for Equivalent Lengths of Pipe

Measured length of run, in feet	124 ft.
Equivalent length for one 2½-in. gate valve	3 ft.
Equivalent length for four 2½-in. elbows	28 ft.
Total Equivalent Length	155 ft.

Work Problems S-3-2, S-3-3, S-3-4

PIPE CAPACITIES FOR STEAM HEATING

The material presented in the preceding lesson, on the flow of steam in pipes should be considered as a steam-supply problem, while the sizing of a system of piping throughout a building is properly termed a steam-distribution problem. The first is to get the steam, in sufficient quantity, to a place where it may be used, while the second is to

provide proper means for using it. The first part of the problem relates mainly to medium and large installations. The second part of the problem relates to the small, medium and large installations.

Velocity of steam flow is a part of the problem of steam supply and a vital part of that of steam distribution. In the case of steam supply, the velocity of flow depends upon the drop in pressure between the ends of the flow line and, therefore, may have a fairly wide range. In the case of steam distribution, the velocity is limited by what is known as the critical velocity. This velocity for a given size pipe and conditions attending the use of steam through that pipe is that which will not be high enough to hinder proper separation of the water of condensation from the steam and the flow of each of the quantities in such manner as to assure uniform circulation.

If the critical velocity is exceeded in the smaller mains, branches, and other piping, water hammer will occur. Critical velocity also bears consideration in larger supply mains, for if steam mains are carrying maximum loads and the steam is flowing at a velocity very much above the critical velocity, the water, instead of draining from the main through drips located at regular intervals, will be carried along and driven into the branch lines. It is therefore important that velocities always be considered.

Work Problem S-3-5

The following velocities for the conditions stated are considered good practice: 16 ft. per second for supply mains, branches, and risers where the condensation and steam are flowing in opposite directions, or for one-pipe up-feed risers; 10 to 20 ft. per second for radiator branches, the lower value being used for small and the higher for the larger pipe sizes where the length does not exceed 5 ft.; 10 ft. per second for radiator branches between 5 and 10 ft. long.

Work Problem S-3-6

SELECTING PIPE SIZES

The sizing of pipes for a steam heating system embodies a consideration of many factors and the size selected is in turn controlled by definite considerations.

The radiator gives off or emits heat in proportion to the quantity (pounds) of steam that is condensed in unit time, sufficient steam must be delivered to the radiator in unit time so that the latent heat of evaporization available from that condensed will meet requirements; the pressure at the boiler and pressure drop between boiler and radiator must be such (for the size pipe used) as to assure the necessary amount of steam being delivered and the piping must be amply large to permit this quantity to flow to the radiator and water to flow from the radiator in an even, quiet and proper manner.

Rate of condensation in radiators, total pressure drop between the boiler and the farthest radiator and the size and grading of pipe thus become most important factors.

Steam radiators under normal operating conditions are considered to condense 0.25 lb. of steam per square foot per hour and this value is taken as the basis upon which to establish tables for selecting pipe sizes.

A total pressure drop of not more than 2 oz. between the boiler and the farthest radiator is considered good practice.

The grade of mains and branches should be not less than as given in the following tabulation:

	Grade, Inches per	Feet
Supply Mains	1	20
Wet Return Mains	1	20
Dry Return Mains	1	20
Horizontal Branches	1	5

Supply mains should be no smaller than 2 in. (except in vary rare instances). A supply main greater than 2½ in. at the boiler should be no smaller than 2½ in. at its end.

The following are recommended as minimum sizes of pipe to use for mains and risers as stated:

	Pipe Size, In. Diam.
Dry return mains	1
Wet return mains	1¼
Supply risers	1
Return risers	¾

Work Problem S-3-7

SELECTING STEAM PIPE SIZES

In the preceding consideration of the flow of steam in pipes and the selection of a pipe size, it was presupposed that the quantity of steam required was known, as well as the other necessary factors. In designing steam mains for large installations, calculations invariably involve quantities of steam required. For strictly steam heating layouts of small and medium size, the actual quantity of steam required, expressed as such, is seldom determined. The latent heat available in the steam is used in the radiator and the size or area of the radiators has been established to meet the heating requirements. Therefore, a selection of pipe sizes based on the radiating surface supplied becomes the logical method of performing such work. Pressure losses, however, affect materially the amount of radiation that may be supplied by a given size pipe.

Best practice in the design of steam mains permits a drop in pressure of 1 oz. per 100 ft. of straight pipe. Satisfactory results for all average installations may be expected when the total pressure drop between the boiler and the farthest radiator is not over 2 oz.

Table S-3-2 shows capacities of pipes in square feet of radiation per 100-ft. run on the basis of a condensation of 0.25 lb. of steam per square foot of direct radiation per hour, with allowance for condensation in covered piping and steam and water flowing in the same direction. This table may be used in several ways.

Thus, if the pressure drop is 1 oz. and the total direct steam radiation is 900 sq. ft., since the

TABLE S-3-2

CAPACITIES OF PIPES IN SQUARE FEET DIRECT RADIATION

BASED ON 100 FT. OF STRAIGHT PIPE OR EQUIVALENT AND ¼ LB. CONDENSATION PER SQ.FT. PER HOUR

PRESSURE LOSS OZ. PER 100 FT.	PIPE SIZE - INCHES											
	¾	1	1¼	1½	2	2½	3	3½	4	4½	5	6
0.25	12	23	51	79	158	262	480	717	1014	1379	1887	3078
0.50	16	32	71	111	224	370	678	1013	1433	1949	2667	4352
1.00	23	46	101	157	316	524	959	1431	2027	2757	3773	6156
1.50	28	56	124	192	387	641	1174	1754	2481	3374	4618	7535
2.00	32	64	142	222	447	741	1356	2026	2866	3898	5334	8704
2.50	36	73	160	248	500	829	1517	2266	3205	4358	5964	9732
3.00	39	79	175	272	548	908	1662	2482	3511	4774	6534	10662
3.50	43	86	189	293	591	980	1794	2680	3790	5155	7055	11511
4.00	46	91	202	314	632	1048	1919	2886	4054	5513	7543	12312
4.50	48	97	214	333	671	1111	2035	3039	4299	5847	8002	13047
5.00	51	102	226	351	707	1172	2145	3204	4532	6164	8435	13747
6.00	56	112	247	384	774	1283	2349	3509	4964	6751	9349	15346
7.00	60	121	267	415	836	1386	2537	3790	5361	7281	9961	16248
8.00	64	129	286	443	894	1482	2713	4052	5732	7796	10667	17407
9.00	68	137	303	470	949	1572	2878	4299	6012	8167	11223	18337
10.00	72	145	319	496	1000	1657	3033	4532	6410	8716	11928	19464
11.00	76	152	335	520	1049	1738	3181	4721	6707	9101	12211	20317
12.00	79	159	350	543	1095	1815	3334	4963	7020	9548	13068	21324
13.00	82	165	364	565	1140	1889	3461	5161	7308	9929	13589	22168
14.00	85	172	378	587	1183	1960	3588	5360	7580	10310	14110	23012
15.00	88	178	391	607	1226	2029	3713	5546	7843	10668	14598	23819
16.00	91	184	404	627	1265	2096	3838	5732	8108	11026	15086	24624

radiation value lies on the 1-oz. pressure-drop line between the values for a 2½-in. and 3-in. pipe, respectively, the larger size pipe or 3-in. will be required.

Work Problem S-3-8

Also, if a 4-in. pipe is available and a pressure drop of 2 oz. is allowed, by reading the value on the 2-oz. line under the 4-in. pipe, it is noted that 1356 sq. ft. of direct radiation may be supplied.

Work Problem S-3-9

Also, if a 2½-in. pipe is supplying 775 sq. ft. of direct radiation, by following down the vertical column for 2½-in. until the lowest value above 775 is reached, which is 829 sq. ft., the equivalent pressure-drop may be read on the horizontal line of 2.5 oz.

Work Problem S-3-10

Since Table S-3-2 is based on a length of 100 ft., to use the table for any other length, a correction must be applied. Correction factors are contained in Column 4 of Table S-2-1. Consequently, if a 3-in. steam main is 120 ft. long and its capacity for a pressure-drop of 2 oz. is desired, the correction factor of 0.912, from Table S-2-1, indicates a capacity of

1356 (sq. ft. from Table S-3-2) x 0.912 (from Table S-2-1) = 1237 sq. ft.

Work Problem S-3-11

Or, if the pressure loss and capacity of a 2½-in. pipe 140 ft. long, supplying 800 sq. ft. of direct radiation, is desired, it may be found by multiplying the pressure-loss per 100 ft. (in this case 2.5 oz.) by the length of pipe in feet, divided by 100. Thus 2.5 x 1.40 = 3.5 oz.

Work Problems S-3-12, S-3-13

SIZING PIPES BY QUANTITY OF RADIATING SURFACE

Where the amount of radiating surface required is known, it is quite easy to proportion the piping by means of tables. Tables S-3-3 to S-3-8 were pre-

pared for this purpose. However, before a table can be used intelligently, one should have a thorough knowledge of the basis of the computations from which it was made.

These tables have been calculated on the assumption that water occupies one-eighth the area of the pipe. In Table S-3-3 is given the size of valves for radiators connected up as one-pipe work. The sizes are based on standard practice for one-pipe systems.

TABLE S-3-3

RADIATOR VALVE SIZES REQUIRED

SQUARE FEET RADIATION	VALVE SIZE INCHES
1 TO 24	1
25 TO 60	1¼
61 TO 100	1½
101 TO 200	2

TABLE S-3-4

ARMS, SMALL BRANCHES AND UP-FEED RISERS TO RADIATORS

SQUARE FEET RADIATION	PIPE SIZE INCHES	
	1 TO 5 FT.	5 TO 10 FT.
1 TO 24	1	1¼
25 TO 60	1¼	1½
61 TO 100	1½	2
101 TO 200	2	2

TABLE S-3-5

STEAM MAINS (NOT OVER 100 FT.) LARGE BRANCHES (DRIPPED) WATER AND STEAM FLOW IN SAME DIRECTION

SQUARE FEET RADIATION	PIPE SIZE INS.
1 TO 40	1
41 TO 75	1¼
76 TO 150	1½
151 TO 300	2
301 TO 500	2½
501 TO 900	3
901 TO 1500	3½
1501 TO 2000	4
2001 TO 3600	5
3601 TO 6000	6

TABLE S-3-6

STEAM MAINS (NOT OVER 100 FT.) LARGE BRANCHES (NOT DRIPPED) UP-FEED RISERS WATER AND STEAM FLOW IN OPPOSITE DIRECTIONS

SQUARE FEET RADIATION	PIPE SIZE INS.
1 TO 40	1
41 TO 75	1¼
76 TO 100	1½
101 TO 170	2
171 TO 220	2½
221 TO 340	3
341 TO 460	3½
461 TO 600	4

In Table S-3-4 the size of horizontal runouts to radiators should be taken. They are based on velocities ranging from 10 to 19 ft. per second depending upon the size of the branch—the smaller

branches having the lower velocities. Branches from 5 to 10 ft. long are based on a velocity of approximately 10 ft. per second. Condensation is assumed as flowing counter to the steam.

Table S-3-5 is based on a pressure drop of 1 oz. per 100 ft. of pipe or equivalent.

Table S-3-6 is based on a velocity of 16 ft. per second.

Table S-3-7 is calculated by the Chezy formula for flow in open conduits.

Table S-3-8 is calculated on a drop of ½ oz. per 100 ft. length of pipe or equivalent.

TABLE S-3-7

DRIPS FOR RISERS		
STEAM RISER SIZE	DRIP SIZE TO RETURN	
	WET	DRY
1	3/4	3/4
1 1/4	3/4	3/4
1 1/2	3/4	1
2	1	1
2 1/2	1	1 1/4
3	1	1 1/4
3 1/2	1 1/4	1 1/2
4	1 1/4	1 1/2

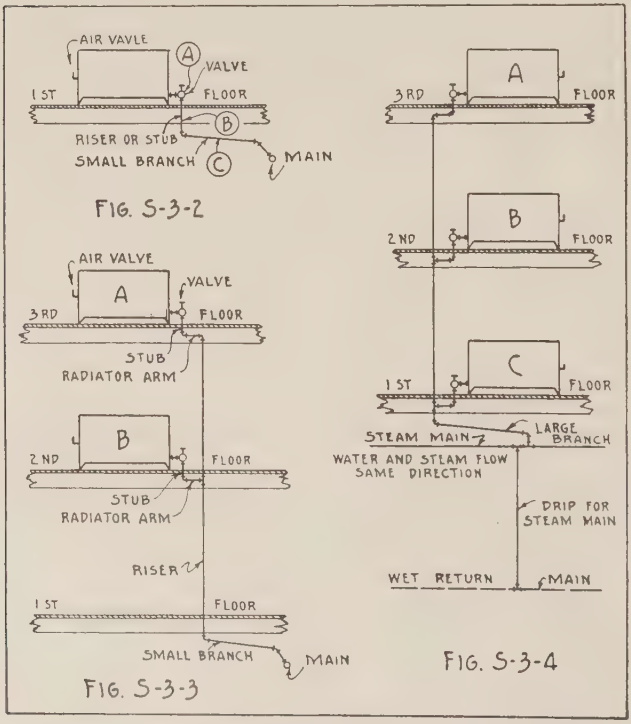
TABLE S-3-8

RETURN MAINS				
SQUARE FEET RADIATION			WET	DRY (NOT OVER 400 FT.) GRADE NOT LESS THAN 1 IN. TO 30 FT.
1	TO	180	-	3/4
181	TO	420	1	1
421	TO	800	1	1 1/4
801	TO	900	1 1/4	1 1/4
901	TO	1500	1 1/4	1 1/2
1501	TO	1800	1 1/4	2
1801	TO	3000	1 1/2	2
3001	TO	4900	2	2 1/2
4901	TO	6000	2	3
6001	TO	9000	2 1/2	3
9001	TO	10000	2 1/2	3 1/2
10001	TO	13000	3	3 1/2
13001	TO	18000	3	4
18001	TO	26000	3 1/2	-
26001	TO	37000	4	-

SIZING PIPES FOR ONE-PIPE WORK

Tables S-3-3 to S-3-8, inclusive, are suited to one-pipe steam distribution problems.

Fig. S-3-2 shows a first-floor radiator as it might be connected for one-pipe work. Knowing the radiating surface of this radiator there are three sizes of pipe to be established between the main and the branch. Tables S-3-3 and S-3-4 should be used. If the radiator contains 50 sq. ft. of surface, the valve size A, by Table S-3-3, should be 1¼ in.; the riser and branch C, by Table S-3-4, should be 1¼ in., unless the branch C should be longer than 5 ft., in which case the branch should be made 2 in. When the radiator is located on the first floor the riser or stub should be the same size as the valve it serves.



Typical Piping Connections for One-Pipe System.

Work Problem S-3-14

Fig. S-3-3 shows two radiators supplied by one up-feed riser. Tables S-3-3 and S-3-4 should be used for determining the sizes for the pipes and valves, bearing in mind that the size of the riser to the radiator arm for the second-floor radiator must be ample to supply both radiators, while above this point it carries steam for only one radiator. The stubs connecting the radiator valve to the radiator arm should be the same size as the valve.

Work Problem S-3-15

Fig. S-3-4 shows a section of a steam main in which steam and water flow in the same direction and the main is dripped at intervals into a wet return.

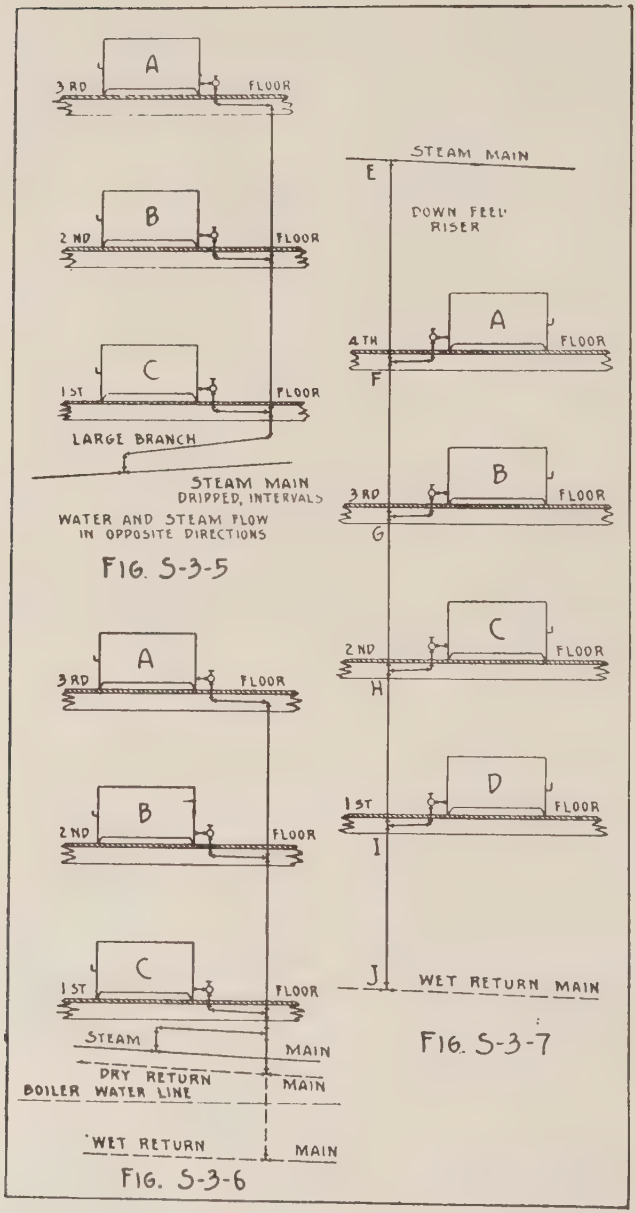
Tables S-3-3 and S-3-4 should be used for determining valve and all pipe sizes from the connection to the main as applied for Figs. S-3-2 and S-3-3, unless the radiation supplied by the branch exceeds 200 sq. ft. In that case, the branch size should be taken from Table S-3-5. To select a size for the steam main, Table S-3-5 should be used. If the total radiation of the three radiators amounts to 325 sq. ft., by this table, the steam main should be made 2½-in.

Work Problem S-3-16

Fig. S-3-5 shows three radiators connected to a steam main in which the steam and water flow in opposite directions. Valve and all pipe sizes from the main to the radiators should be determined by Tables S-3-3 and S-3-4 as previously applied unless the combined radiation is greater than 200 sq. ft., in which case, Table S-3-6 should be used for selecting the branch size. The size for the main should be taken from Table S-3-6, bearing in mind that it must be large enough to supply all radiators connected to it.

Work Problem S-3-17

Fig. S-3-6 shows three radiators supplied by a single riser. In order to relieve the main of the condensation from the radiators, a separate drip is shown connected (by solid line) into a dry return and (by broken line) into a wet return. Table



Layouts Used in Connection With One-Pipe Heating Problems

S-3-7 should be used for determining the size pipe to use for this drip connection, paying due attention to the kind of return main into which it delivers. All other pipe sizes should be selected as previously explained. Note that Table S-3-7 gives drip sizes in terms of steam riser size and not in terms of radiation.

Work Problem S-3-18

Return main sizes may be obtained from Table S-3-8.

Work Problem S-3-19

Tables S-3-5 and S-3-6 are applicable to supply mains not exceeding 100 ft. in length. If a supply main is longer than 100 ft., its capacity should be reduced accordingly by applying factors given in column 4 of Table S-2-1.

Work Problem S-3-20

Reference to Fig. S-2-4 shows that the risers are down-feed. Consequently each must carry steam sufficient to supply the radiators and the water of condensation therefrom. They may be proportioned by using Table S-3-5 and modifying the radiation as follows: Add to the radiation for which steam is to be supplied by the given length of pipe, one-fourth of that for which condensation must also be handled in the same pipe. Thus in Fig. S-3-7, the section of the down-feed riser from E to F will be sized by the amount of radiating surface for radiators A, B, C, and D; section FG for the radiating surface of B, C, and D increased by one-fourth of that of A, and so on. Section IJ will be sized as a drip for the combined radiation A, B, C, D.

Work Problem S-3-21

Fig. S-3-8 shows details of a straight one-pipe heating system. The student will apply the data given in Tables S-3-3 to S-3-8 so as to present a design from which an estimate may be prepared and the installation made. This represents the cheapest type of steam heating system. The following problems exemplify not only the application of the above tables, to a simple design problem, but show that the effect of fittings in the line must be considered and how important this becomes with a system of this kind.

Work Problems S-3-22, S-3-23

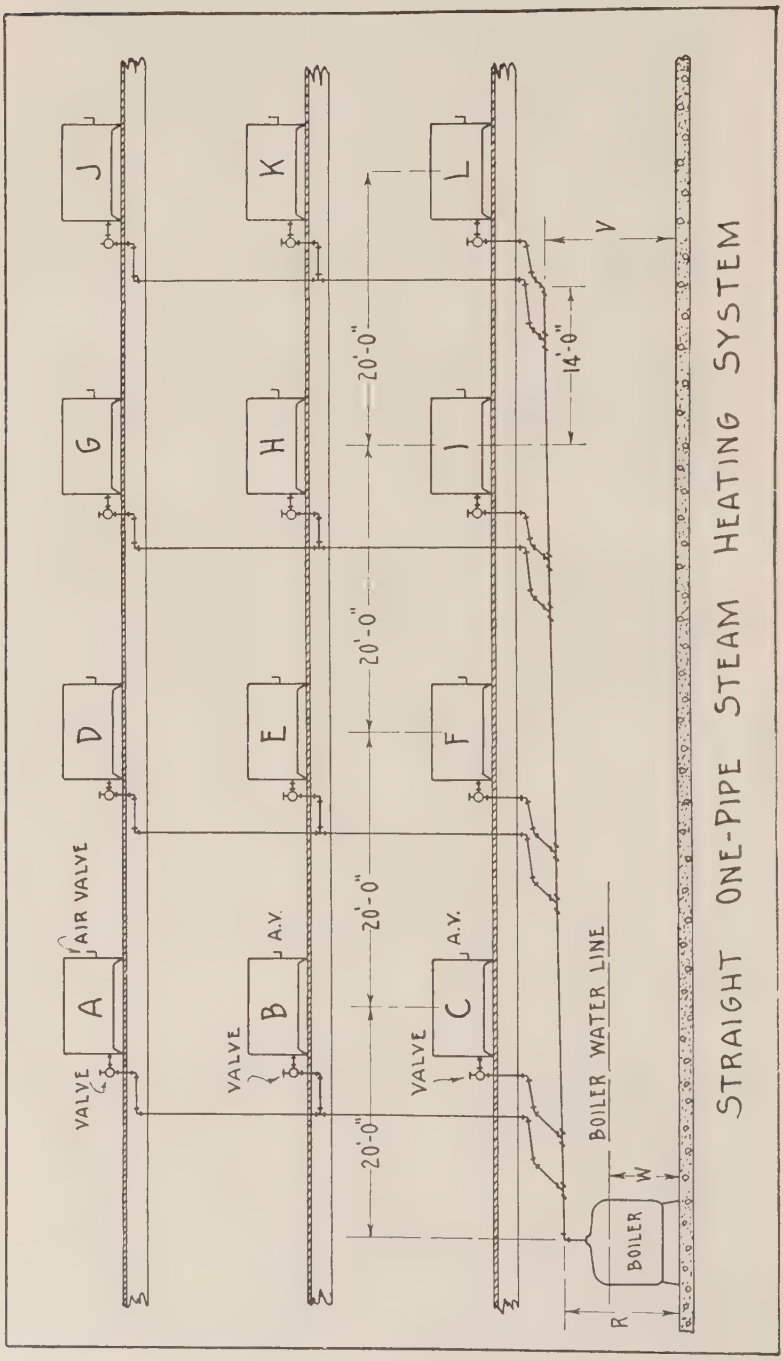

STRAIGHT ONE-PIPE STEAM HEATING SYSTEM
AIR VALVE
A.V.
A.V.
VALVE
VALVE
VALVE
A
B
C
D
E
F
G
H
I
J
K
L
20'-0"
20'-0"
20'-0"
20'-0"
14'-0"
V
BOILER WATER LINE
BOILER
R
W

Fig. S-3-8

PART S.

STEAM HEATING SYSTEMS

LESSON 4.

Typical Applications

STEAM HEATING SYSTEMS.

ONE-PIPE CIRCUIT SYSTEM.

A typical piping run for the one-pipe low-pressure gravity circuit system of steam heating with wet return is shown in Fig. S-4-1. This is probably the most common system of one-pipe steam heating. The steam main rises just above the boiler to a point close to the basement ceiling as at M and then grades down uniformly from this high point with a fall or pitch of about 1 in. (or slightly more if height is available) in 10 ft. of run. After serving the last radiator, the main drops as at N and O and runs back to the boiler. It may be carried higher than the water line in the boiler (as shown by a light dotted line) as a dry return, or after supplying the last radiator, it may drop to a lower point

as at P (such that the proper pitch can be maintained to the boiler entrance) and run back lower than the water line in the boiler as a wet return (see heavy dotted line). As a wet return it carries only condensation.

Return piping should be graded about 1 in. in 20 to 30 ft. in gravity work. An automatic air valve should be installed on the end of the main where it drops, as shown at N.

The distance or height (represented by Q) of the end of the main as at N above the boiler water line must be carefully determined in order that water may not back up from the boiler through the return main and flood the steam main or part of it, air valves and branches.

The determination of this height Q will be fully covered in a succeeding lesson. At this time it should be remembered that the height at this point of the system has much to do with success or failure of the installation.

It is customary to maintain at least 12 in. and, preferably, 18 in. between the under side of the main at the drop point and the normal water line of the boiler. Provision should be made to guard against the possibility of water leaving the boiler when first starting up. The check valve installed in the return is the more common method of preventing water from leaving the boiler when the pressure is raised suddenly. This is liable to happen when first starting up the system. At such time, the pressure drop is greatly increased, due to the rapid passage of steam through the piping and the large amount of condensation resulting from the low temperatures of the radiators.

As the steam condenses in the system, a partial vacuum tends to form in parts of the system far from the boiler, and as pressure within the boiler is exerted in all directions, downwards with as much force as upwards, the water, unless checked, will be forced downward and out through the returns. The purpose of the check valve is to prevent water being forced out of the boiler, pending the restoration of a normal pressure difference between the boiler and end of the system—and the check valve performs this function fairly well, providing the condition is not of too long duration.

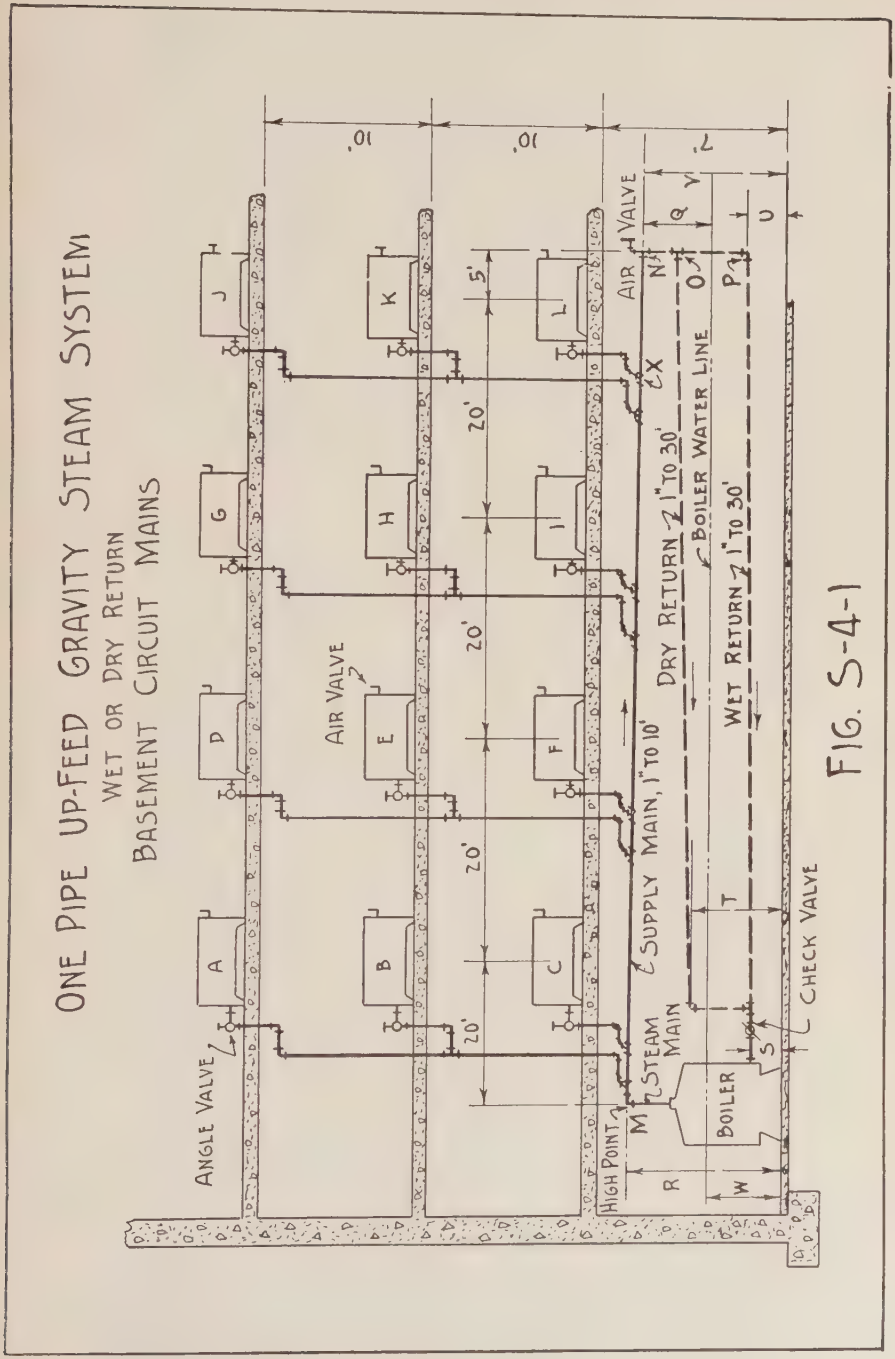

ONE PIPE UP-FEED GRAVITY STEAM SYSTEM
WET OR DRY RETURN
BASEMENT CIRCUIT MAINS
ANGLE VALVE
AIR VALVE
AIR VALVE
STEAM MAIN
SUPPLY MAIN, 1" TO 10'
DRY RETURN 1" TO 30'
BOILER WATER LINE
WET RETURN 1" TO 30'
HIGH POINT
BOILER
CHECK VALVE
10'
10'
7'
5'
20'
20'
20'
20'
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X

FIG. S-4-1

If the radiators are exceptionally cold and the abnormal pressure difference persists, the water will accumulate in the returns, back of the check valve, until a height sufficient to overcome the pressure difference occurs in the returns. This may actually mean a considerable quantity of water, depending upon the length of the piping runs. It may amount to enough to lower the water line in the boiler so much as to cause damage to the boiler.

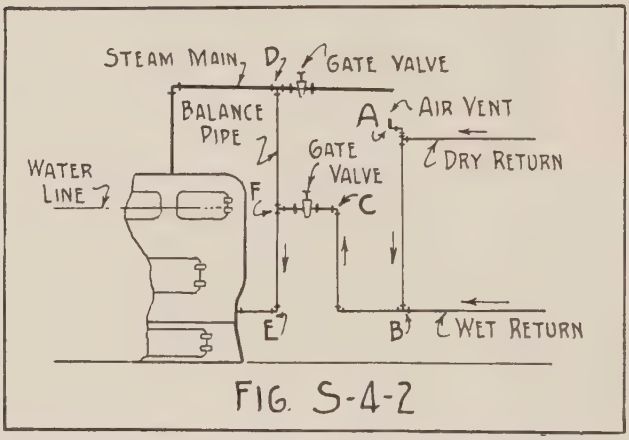


Fig. S-4-2. Piping at Boiler for Equalizing Pressure in Supply and Return Main

Fig. S-4-2 shows a much better method for making the connections at the boiler. It may be applied to either one- or two-pipe jobs having either wet or dry returns. The steam mains and returns are run as explained in this and succeeding lessons. The arrangement of the piping to accomplish the desired result is made at the boiler. The return is vented as shown at A and dropped to a point B on a line with the return opening into the boiler. It is then brought upwards to C to form a water seal. This point C is located at a height corresponding to the height of the water line of the boiler. A line is run (from D to E) connecting into the steam main at D and extending vertically downwards to the level of the return on boiler at E. In this line a tee, F, is located as shown and into its side opening, the return from C is connected. From Point F, this pipe carries all the condensation in the system.

Thus the escape of water through the return is prevented should a sudden increase of pressure in the boiler or decrease of pressure in the returns occur, or in case both conditions should happen at the same time. The boiler pressure is exerted both at the bottom and top of the column DE and thus effectively prevents the backward movement of the water. In case the pressure difference is great enough, the water will be forced downward in the central column from C and steam will move over into the dry return sufficiently to restore the pressure, less the difference in height pressure as represented by the distance from the water line to the dry return.

Work Problem S-4-1

Low-pressure heating jobs are sometimes fitted with a pressure-reducing valve at the boiler. If this is not done and the only means of producing a pressure drop in the system is by condensation and friction, it is good practice to drip the end of the return at the boiler, providing the last connection taken off is not too far away. When the distance is so great as to cause the cost of pipe and pipe covering to be a considerable item of expense, it is well to end the steam main at the last connection and continue full size to a full-size ell and drip it as shown in Fig. S-4-3. Another form of drip connection that is much used is shown in Fig. S-4-4. Since this arrangement leaves the diaphragm of the trap in almost constant contact with steam, the result is likely to be chattering or other objectionable noise. The arrangement of Fig. S-4-3 is believed better since the trap is submerged most of the time. The gate valve for gaining access to the trap for cleaning may be placed in the reduced size dirt pocket, and thus permit cleaning without lowering the pressure in the system.

Work Problem S-4-2

Since in the system shown in Fig. S-4-1, the steam main carries steam and water, for small installations the pipe should be run full size from boiler to the end of the main, using tables given in the preceding lesson for determining sizes.

Work Problems S-4-3, S-4-4, S-4-5

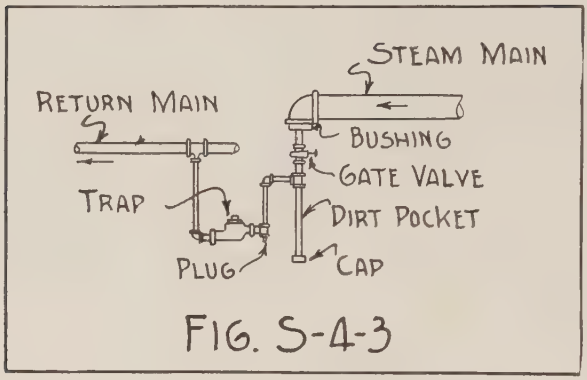


Fig. S-4-3. Drip Piping at End of Steam Main Preferred to that of Fig. S-4-4

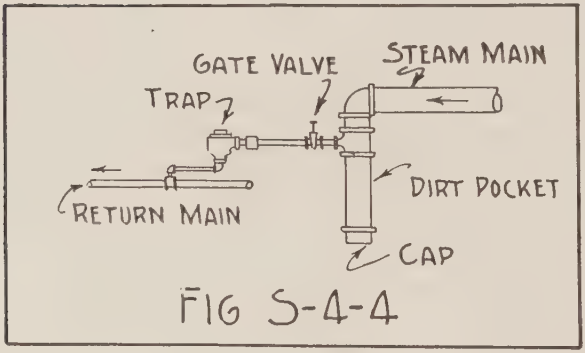


Fig. S-4-4. Alternate Method of Dripping Steam Main at End

Fig. S-4-5 shows a one-pipe low-pressure gravity circuit main system installed in a two-story building. The main branches above the boiler and runs around the two sides of the building with each end dripped into a wet return. Radiation values are assigned in the following problem and the student is to submit a complete piping design for this system, noting all necessary valves and other equipment. In determining the size of the mains, lengths, as given in the problem, and the effect of all fittings are to be considered.

Work Problem S-4-6

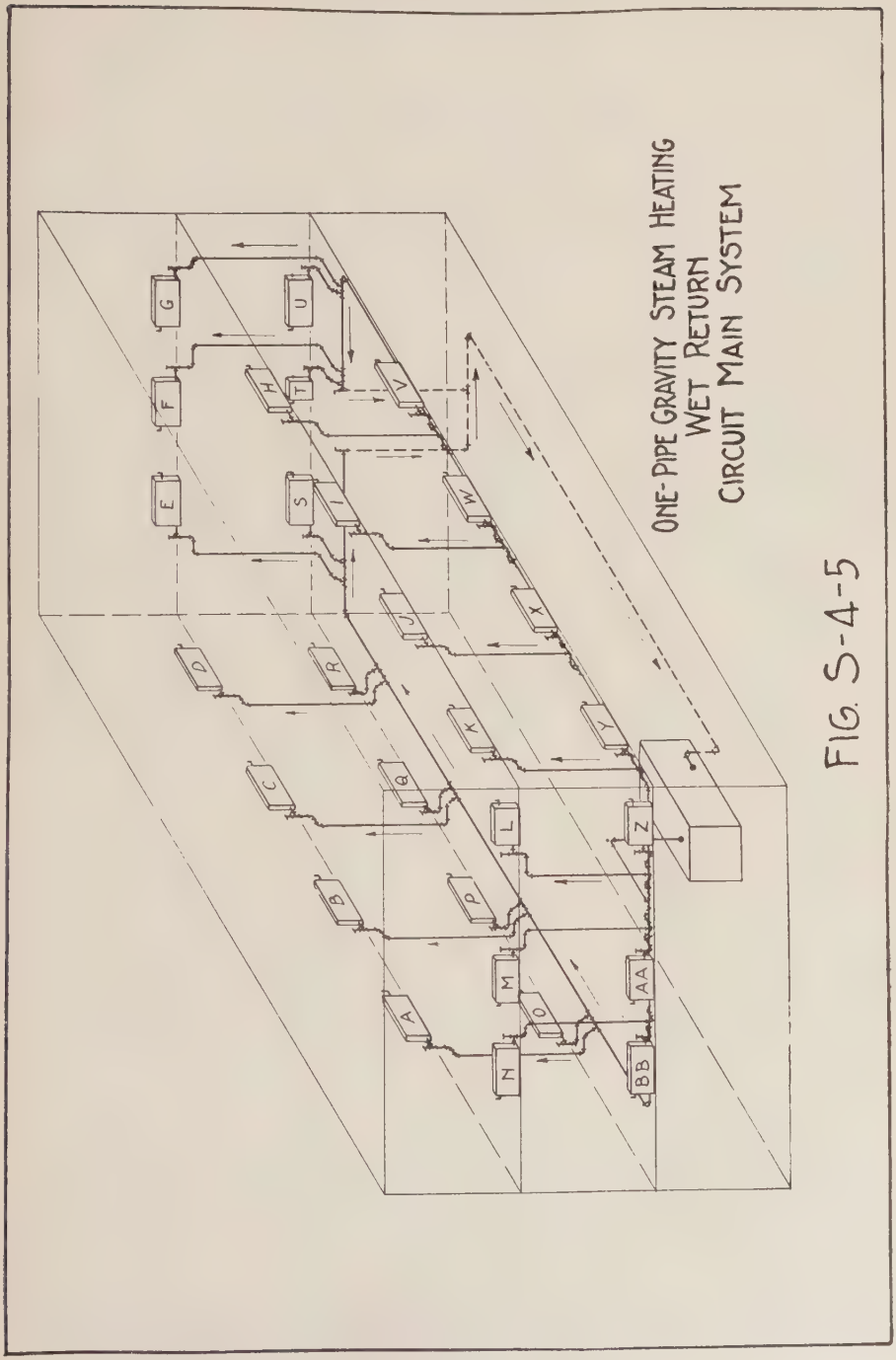

ONE-PIPE GRAVITY STEAM HEATING
WET RETURN
CIRCUIT MAIN SYSTEM
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
AA
BB

FIG. S-4-5

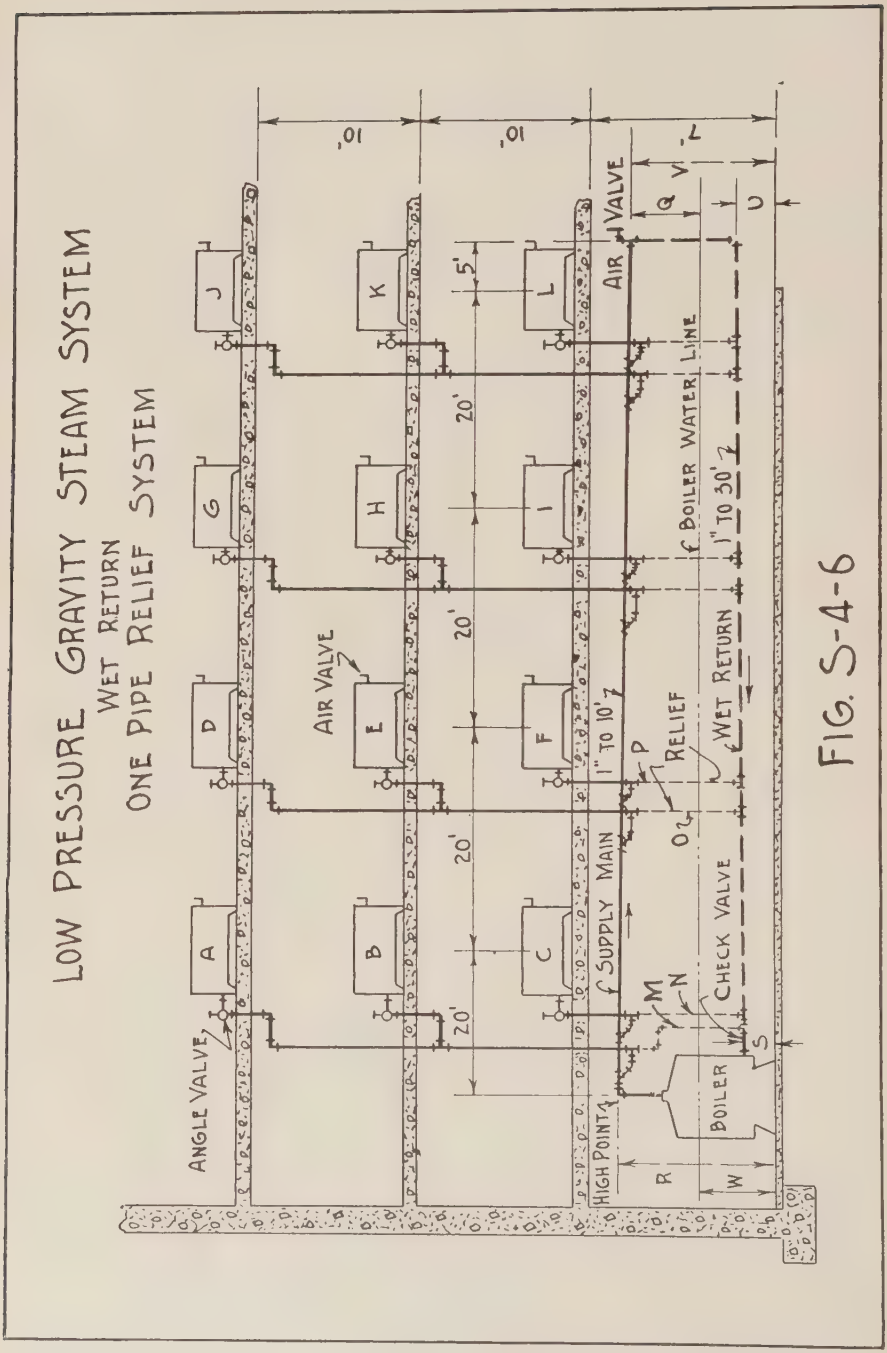

LOW PRESSURE GRAVITY STEAM SYSTEM
WET RETURN
ONE PIPE RELIEF SYSTEM
ANGLE VALVE
AIR VALVE
AIR VALVE
SUPPLY MAIN
HIGH POINT
BOILER
CHECK VALVE
RELIEF
WET RETURN
BOILER WATER LINE
1" TO 10'
1" TO 30'
20'
5'
10'
7'
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
U
V
W

FIG. S-4-6

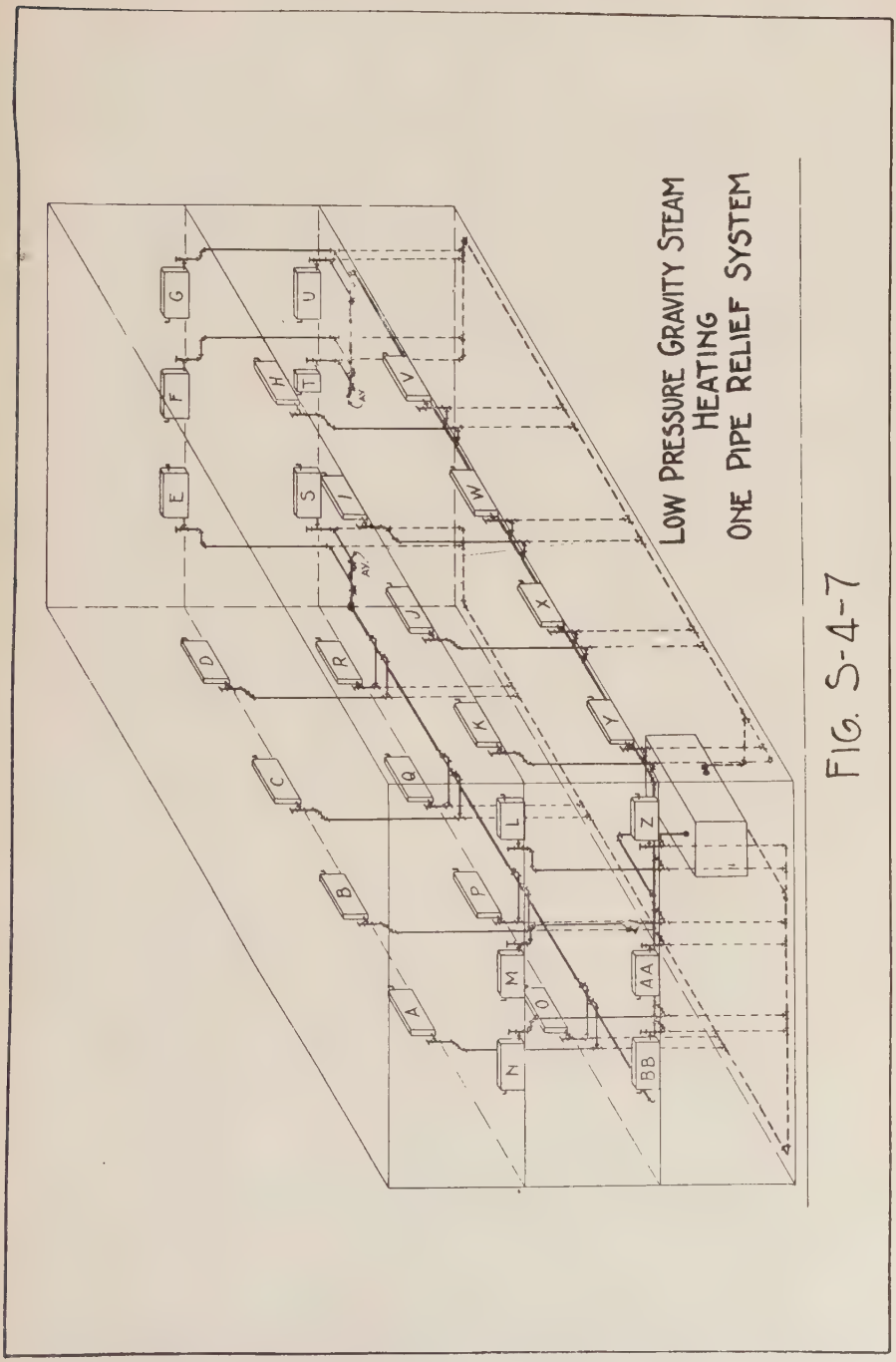

LOW PRESSURE GRAVITY STEAM
HEATING
ONE PIPE RELIEF SYSTEM
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
AA
BB

FIG. S-4-7

ONE-PIPE GRAVITY RELIEF SYSTEM

A typical elevation layout of this system of piping is shown as Fig. S-4-6, while the application is illustrated in Fig. S-4-7.

This system is very similar to the one-pipe circuit system, except that the risers are dripped individually into the return from riser to return, (note the narrow broken lines), the steam main carries no condensation from radiators. It is itself dripped. This permits reducing the size of the main where a branch is taken off and the main is relieved from carrying condensation at each point where there is a take-off for a riser. If the risers are far apart, separate drips are sometimes installed to relieve the main of condensation. The return may be run either wet or dry.

Fig. S-4-8 shows the preferable manner of making connections from the main to riser and connecting the drip line into the wet-return main.

The return mains for the one-pipe relief system are usually run along the walls near the floor or as nearly under the risers as practical. A wet return is preferable, but if a dry return is absolutely necessary, the drips should all be water-sealed, as explained later in connection with a two-pipe dry return gravity system.

Work Problem S-4-7

The sizes of mains, branches, risers and radiator valves may be determined by the proper table given in the preceding lesson. Sizes for the relief pipes should be taken from Table S-4-1. No drips for the main are shown in Figs. S-4-6 or S-4-7 because the radiator branches are far apart. Table S-4-2 may be used for other piping systems when such drips are required.

Work Problems S-4-8, S-4-9

ONE-PIPE OVERHEAD SYSTEM, WET RETURN

A typical elevation layout of this system of piping is shown as Fig. S-4-9. It is applied to a three-story building in Fig. S-4-10. This system as a one-pipe job is to be preferred to an up-feed single-pipe system where the square feet of radiation

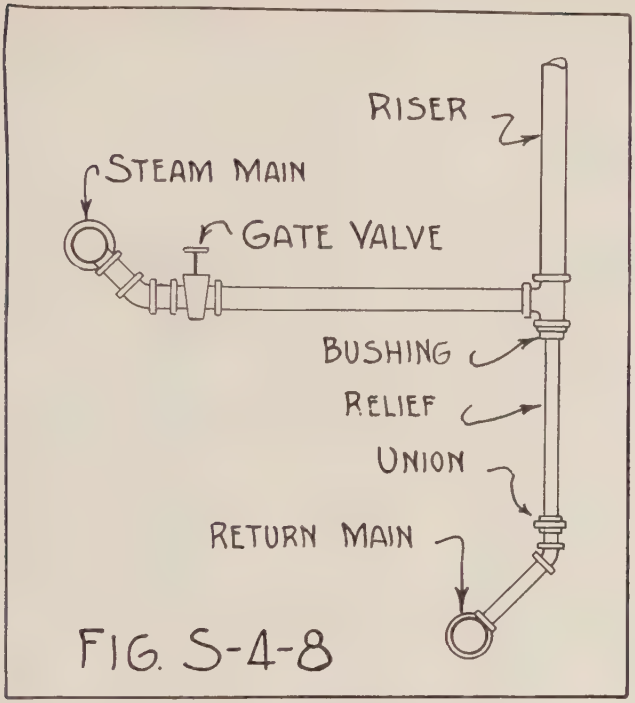


Fig. S-4-8. Piping Connections for Steam Main, Riser and Relief Drip.

TABLE S-4-1
RELIEF SIZES

RISER	1"	1¼"	1½"	2"	2½"	3"	3½"	4"	4½"	5"
RELIEF	¾"	1"	1"	1¼"	1½"	2"	2"	2½"	3"	3"

TABLE S-4-2
DRIP PIPE SIZES

DIAMETER STEAM MAIN INCHES	LENGTH STEAM MAIN - FEET			
	0 - 100	100 - 200	200 - 400	400 - 600
	DIAMETER DRIP PIPE - INCHES			
0 - 2	½	½	½	¾
3	½	¾	¾	1
4	¾	¾	1	1¼
5	¾	1	1¼	1½
6	1	1¼	1½	1½

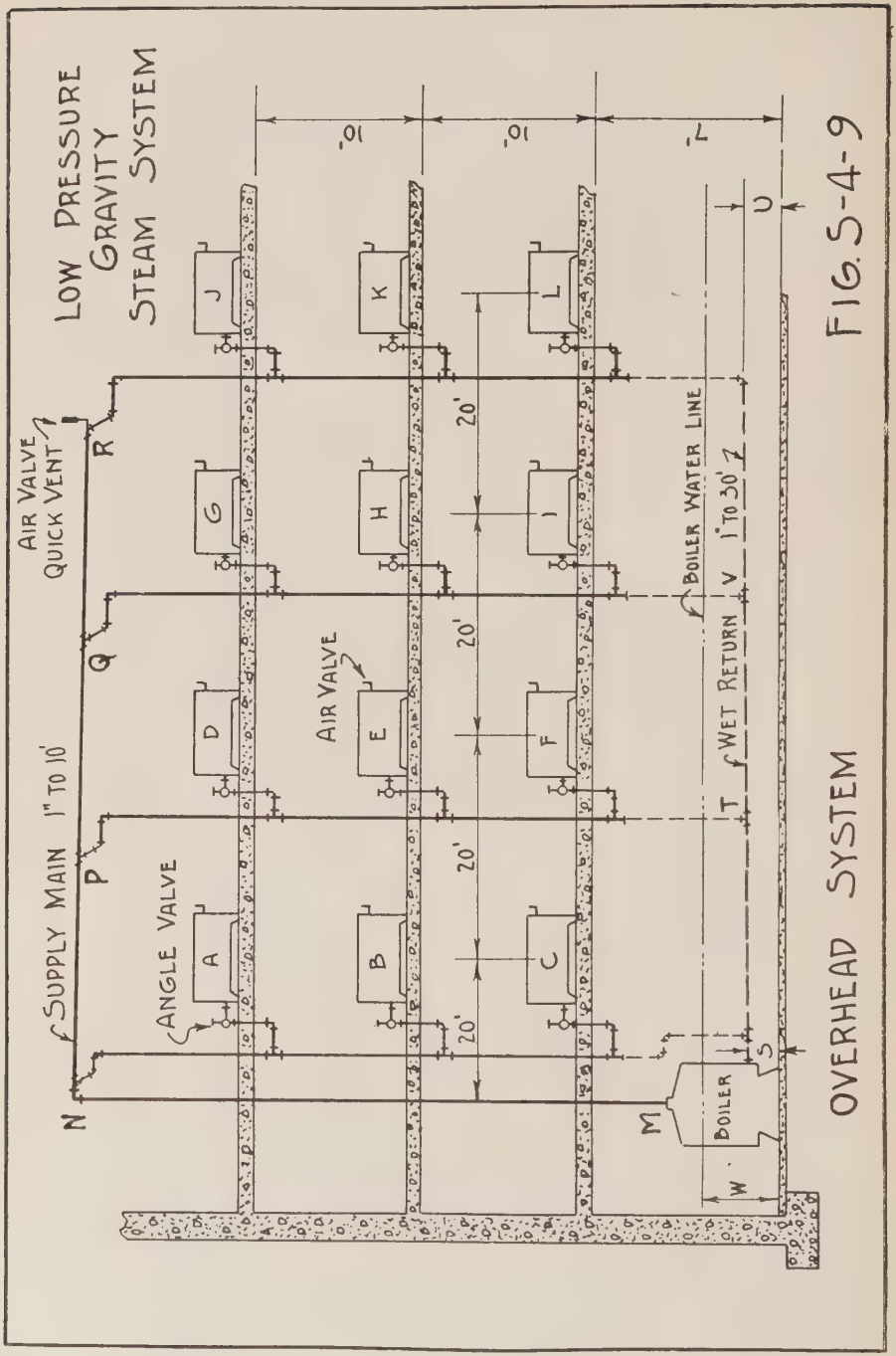

LOW PRESSURE GRAVITY STEAM SYSTEM
AIR VALVE QUICK VENT
SUPPLY MAIN 1" TO 10'
ANGLE VALVE
AIR VALVE
BOILER WATER LINE
WET RETURN 1" TO 30'
BOILER
OVERHEAD SYSTEM
20'
A
B
C
D
E
F
G
H
I
J
K
L
M
N
P
Q
R
S
T
U
V
W

FIG. S-4-9

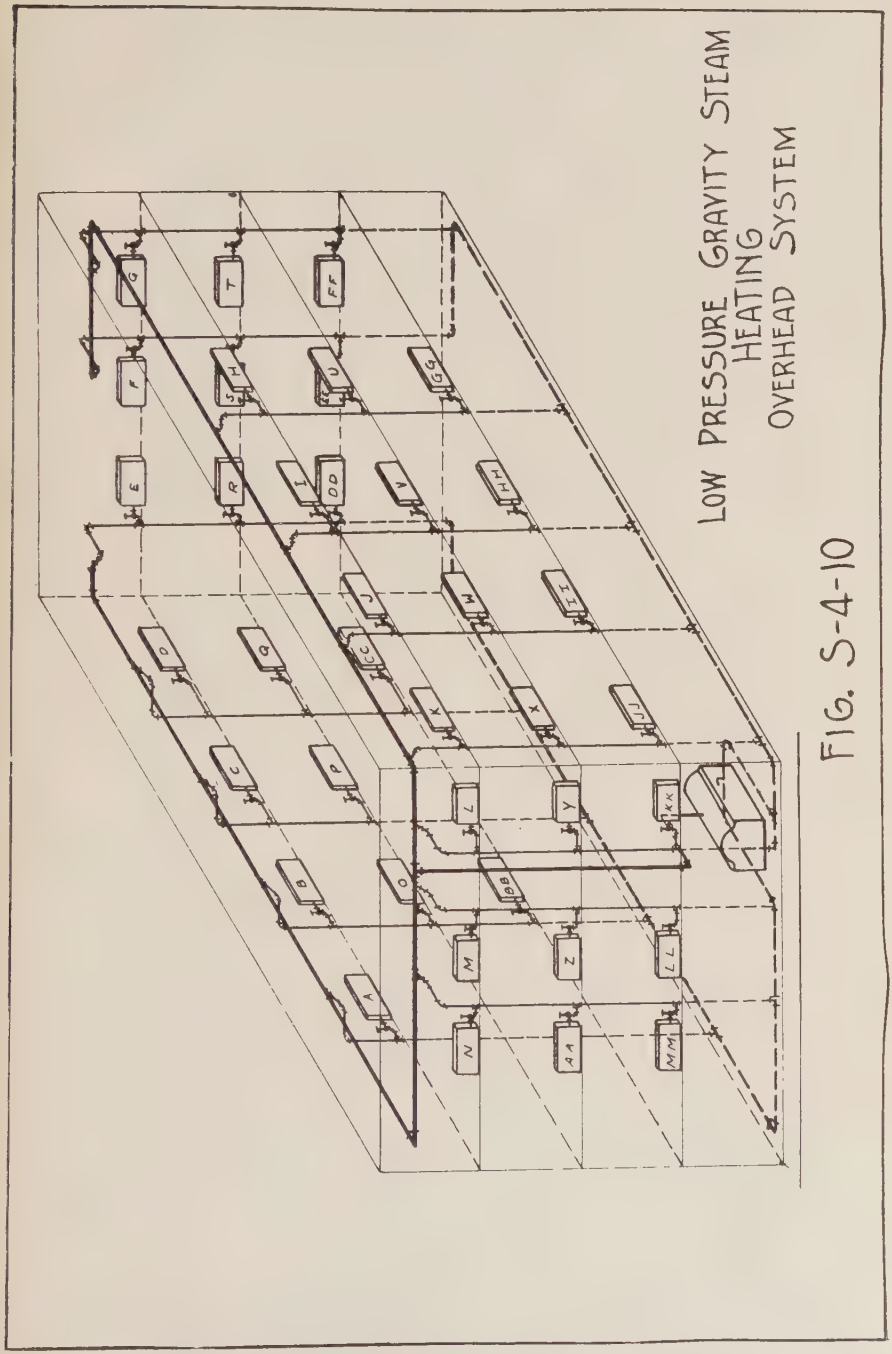


FIG. S-4-10

supplied by a riser is as much as 600 sq. ft. The condensation from this amount of surface, when flowing in a direction opposite to that of the steam, is most likely to result in unsatisfactory service.

This system and the one-pipe relief approach a two-pipe job since each has a steam main and a return main but use only one radiator connection. Referring to Fig. S-4-9, the steam main rises from the boiler at M to a point N, from where an overhead main is run around the ceiling of the top floor or in an attic above. The main pitches down in the direction of the flow. Drop risers are supplied from tees as at P, Q, R, etc., with outlet turned downward 45°. The drop risers supply the radiators and the condensation from them flows back through the radiator connection to the riser, from where it is finally drained through drips into the return main as at T, V, etc.

Work Problems S-4-10, S-4-11

ONE-PIPE OVERHEAD SYSTEM, DRY RETURN

While Figs. S-4-9 and S-4-10 show the overhead system, with a wet return, it is often installed with a dry return. With such an arrangement, no connection from a radiator or a drip from the end of a main or the bottom of a drop riser should be connected into a dry return, without using a radiator trap or horizontal swing check valve for every drip. Fig. S-4-11 shows two methods of making radiator connections (a) with a check valve, (b) with a thermostatic trap. If the connections are not made in a manner similar to one of those shown, the steam will short-circuit through the drip connections and hold back the water of condensation with the result that the pressure on the return will force the water upwards in the drips and risers connected further along the line. A special check valve should be used for this work. The proper valve has a very light weight clapper that hangs in an almost vertical position so that the weight of only a little water is required to open it.

Fig. S-4-12 shows diagrammatically the run of piping for a one-pipe down-feed system that, as laid out, does not function properly. The student will submit a new piping arrangement, properly connected and sized as required in the following problem.

Work Problem S-4-12

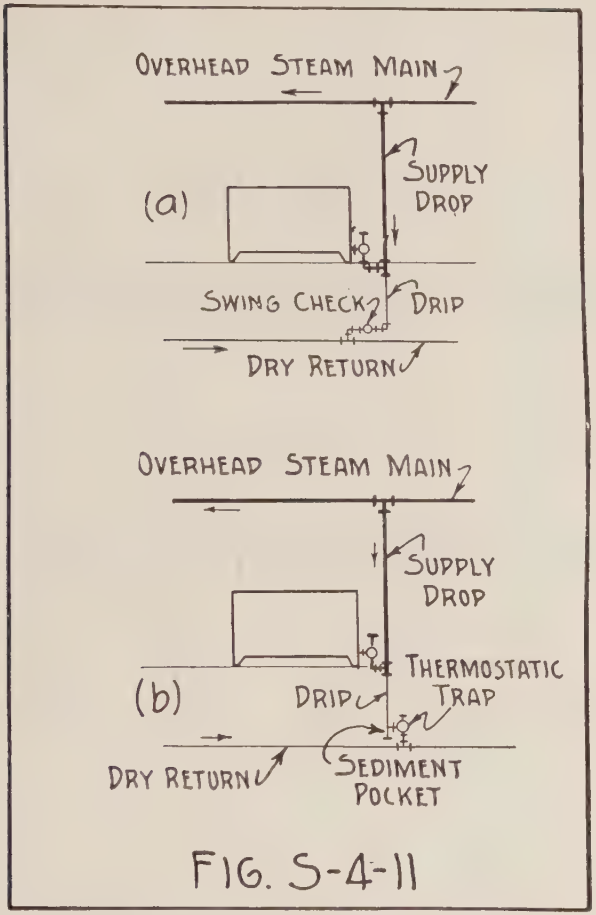


Fig. S-4-11. Piping Connections Between Supply Drop, Radiator and Dry Return

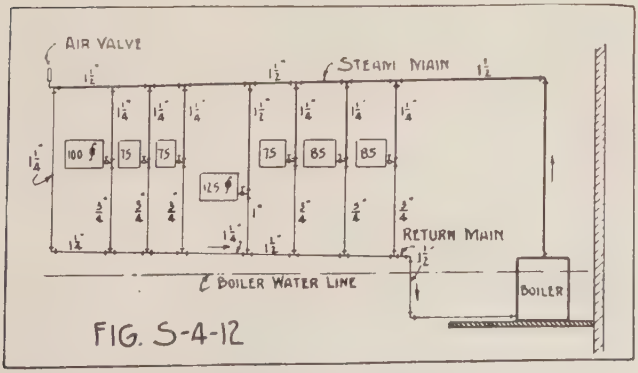


Fig. S-4-12. An Overhead Steam System that Functions Poorly

PART S.

STEAM HEATING SYSTEMS

LESSON 5.

Typical Applications (Continued)

STEAM HEATING SYSTEM.

While straight two-pipe steam heating systems, as shown in the figures accompanying this lesson, are probably the exception, rather than the rule now-a-days, yet many such plants using two valves to a radiator are in use. It is, therefore, essential that the student have available ready data concerning such and be prepared to use same for inspection and report work.

Straight two-pipe steam heating systems may be installed having either a wet or dry return. Fig. S-5-1 shows a wet-return system installed in a two-story rectangular building, while Fig. S-5-2 shows a similar installation with dry return.

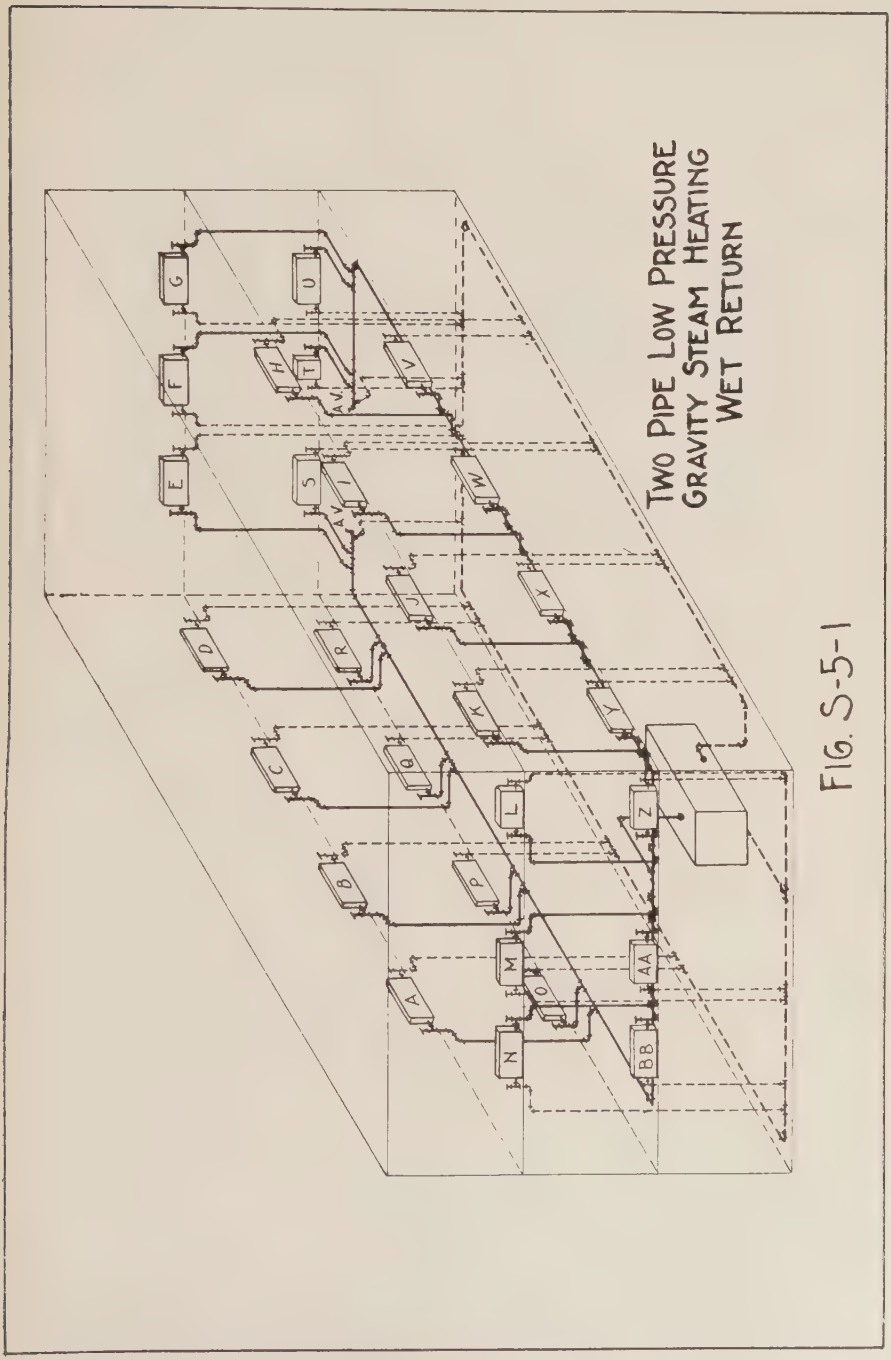

TWO PIPE LOW PRESSURE
GRAVITY STEAM HEATING
WET RETURN
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
AA
BB
AV
AV

FIG. S-5-1

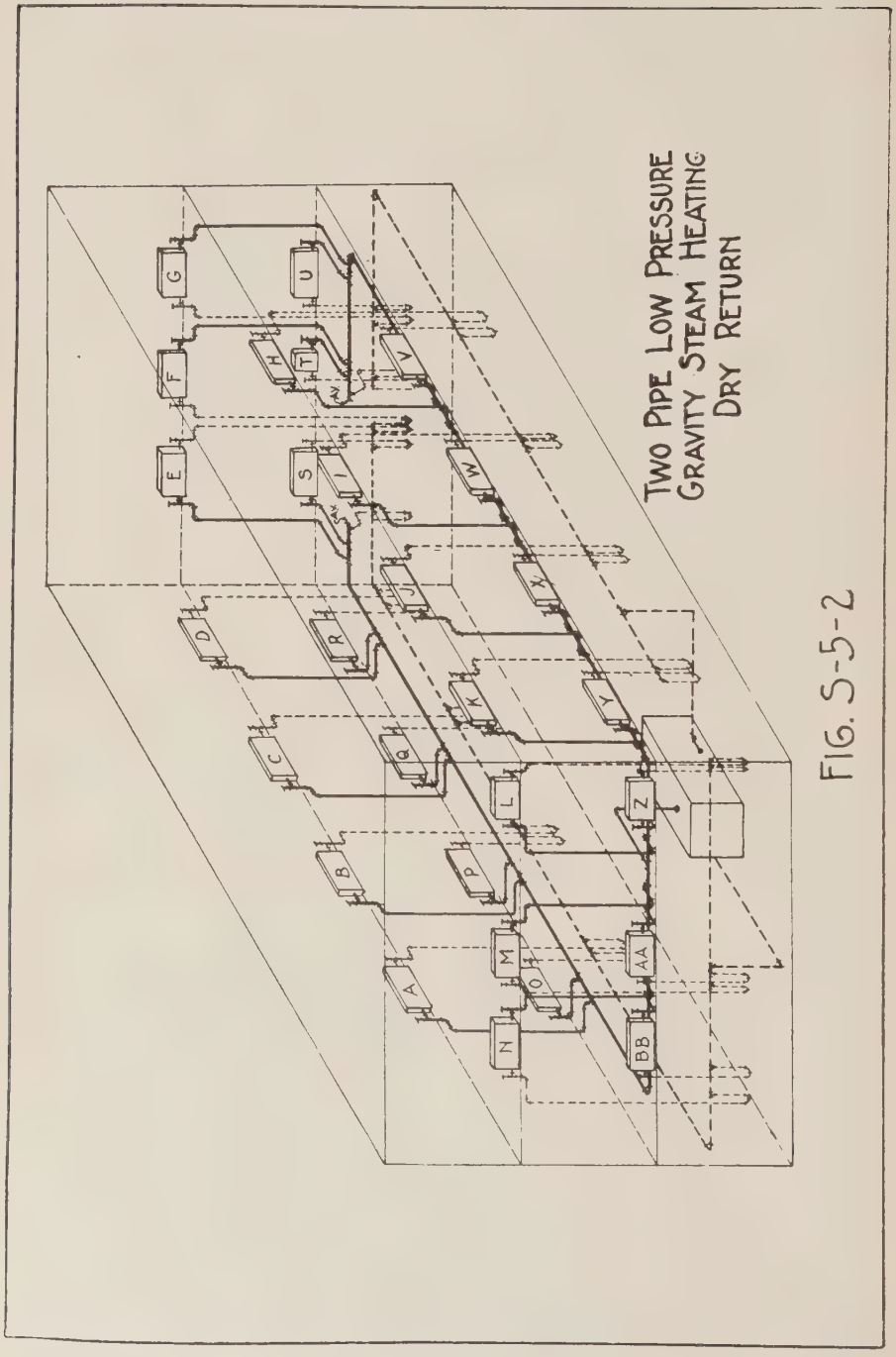

TWO PIPE LOW PRESSURE
GRAVITY STEAM HEATING
DRY RETURN
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R
S
T
U
V
W
X
Y
Z
AA
BB

FIG. 8-5-2

These two-pipe systems are used frequently in large buildings and in practically all work where indirect steam radiation is installed. The system can be readily adapted to mechanical vacuum systems. Two-pipe systems of this type, with either wet or dry returns, require that the return from each radiator be separately sealed.

In the wet-return system, Fig. S-5-1, this is accomplished by carrying the main return below the boiler water-line and connecting each return riser from a radiator into it. Water will stand in these return risers at a height slightly above the boiler water-line and thus seal them so that steam from the steam main cannot pass through the radiator, into the return riser and thence into the return main. With unsealed return risers or drips, steam might enter a drip or return from the radiator outlet end, with a resulting knocking or water-hammer, due to the counter currents of the steam and water of condensation. It should invariably be observed that any drip relief, return riser or connection from the steam to the return side of the system must be sealed. This may be accomplished by connecting below the boiler water-line, as explained, or by using a radiator trap or return trap properly placed in the connecting line.

In the two-pipe dry-return steam system, Fig. S-5-2, the piping is similar to that having a wet return except that drip loops are used to separately seal the return from radiators and drips before connecting into the dry return.

Two-pipe steam-heating systems differ from a one-pipe system in which the main is not dripped in that it may be reduced as rapidly as withdrawal of steam will permit.

SIZING PIPES BY QUANTITY OF RADIATING SURFACE

Similarly, as was explained in Lesson S-3 for one-pipe work, pipe sizes for two-pipe steam heating with either wet or dry returns may be determined from suitable tables. Such tables, numbered S-5-1 to S-5-6 are included herewith and were prepared on the same basis as Tables S-3-3 to S-3-8.

Fig. S-5-3 shows a first-floor radiator as it might be connected for two-pipe work, using a wet return. Knowing the radiating surface of this radiator, there are three lengths of pipe between the main and the radiator to be sized. Tables S-5-1 and S-5-2 should be used. If the radiator contains 70 sq. ft. of surface, the valve size A on the supply side by Table S-5-1 should be 1¼ in.; the stub B should be the same size as the valve A, 1¼ in. for first-floor radiators; the branch C, by Table S-5-2, should be 1½ in. if not longer than 5 ft., or 2 in.

TABLE S-5-1
TWO PIPE STEAM
RADIATOR VALVE SIZES

RADIATION SQ. FT.	SUPPLY INS.	RETURN INS.
1 TO 20	¾	¾
21 TO 40	1	¾
41 TO 80	1¼	1
81 TO 160	1½	1¼
161 TO 320	2	1½

TABLE S-5-2
TWO PIPE STEAM
ARMS-SMALL BRANCHES
UP FEED RISERS

RADIATION SQ. FT.	PIPE SIZE INS.	
	1 TO 5 FT.	5 TO 10 FT.
1 TO 24	1	1¼
25 TO 60	1¼	1½
61 TO 100	1½	2
101 TO 200	2	2

TABLE S-5-3
TWO PIPE STEAM
LARGE BRANCHES
NOT DRIPPED
STEAM MAIN TO RISER
UP FEED RISER
WATER AND STEAM FLOW IN OPPOSITE DIRECTION

RADIATION SQ. FT.	PIPE SIZE INS
1 - 40	1
41 - 75	1¼
76 - 100	1½
101 - 170	2
171 - 220	2½
221 - 340	3
341 - 460	3½
461 - 600	4

TABLE S-5-4
TWO PIPE STEAM
STEAM MAINS
NOT OVER 100 FT.
LARGE BRANCHES
DRIPPED
WATER AND STEAM FLOW IN SAME DIRECTION

RADIATION SQ. FT.	PIPE SIZE INS
1 - 40	1
41 - 75	1¼
76 - 150	1½
151 - 300	2
301 - 500	2½
501 - 900	3
901 - 1500	3½
1501 - 2000	4
2001 - 3600	5
3601 - 6000	6

TABLE S-5-5
TWO PIPE STEAM
DRIPS FOR RISERS

SIZE STEAM RISER	DRIP SIZE TO RETURN	
	WET	DRY
1	3/4	3/4
1 1/4	3/4	3/4
1 1/2	3/4	1
2	1	1
2 1/2	1	1 1/4
3	1	1 1/4
3 1/2	1 1/4	1 1/2
4	1 1/4	1 1/2

TABLE S-5-6
TWO PIPE STEAM
RETURN MAINS

RADIATION SQ. FT.	WET	DRY NOT OVER 4.00' GRADE AT LEAST 1"-30'
1 - 180	-	3/4
181 - 420	1	1
421 - 800	1	1 1/4
801 - 900	1 1/4	1 1/4
901 - 1500	1 1/4	1 1/2
1501 - 1800	1 1/4	2
1801 - 3000	1 1/2	2
3001 - 4900	2	2 1/2
4901 - 6000	2	3
6001 - 9000	2 1/2	3
9001 - 10000	2 1/2	3 1/2
10001 - 13000	3	3 1/2
13001 - 18000	3	4
18001 - 26000	3 1/2	-
26001 - 37000	4	-

if that length is exceeded. On the return side, valve D, by Table S-5-1, should be 1 in.; the stub E, 1 in.; and arm F, 1 in.

Work Problem S-5-1.

Fig. S-5-4 shows a first-floor radiator with return sealed to the dry-return main. Pipes may be sized by Tables S-5-1 and S-5-2, as for Fig. S-5-3.

Work Problem S-5-2.

Fig. S-5-5 shows a section of a steam and a return main, with connections to radiators on a second and third floor. The return is run wet. When the combined area of radiators A and B is as much as 200 sq. ft., or as compared with other radiator groups of the same system the supply branch would be considered large, pipe sizes should be obtained from Table S-5-3, otherwise from Table S-5-2.

Work Problem S-5-3.

Fig. S-5-6 shows a radiator group where a dry return is used. Tables S-5-1, S-5-2, and S-5-3 are used for sizing this arrangement, similarly as for Fig. S-5-5.

Work Problem S-5-4.

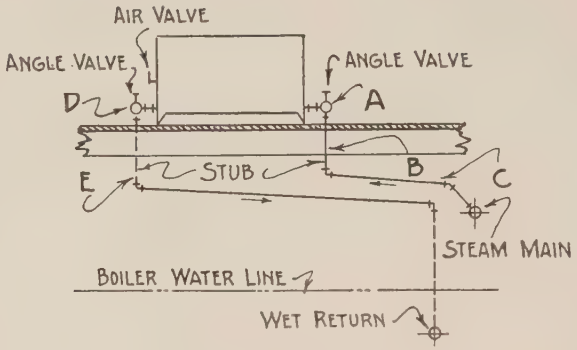


FIG. S-5-3

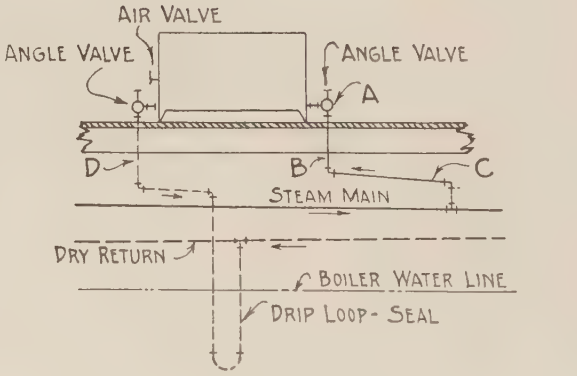


FIG. S-5-4

Two-pipe systems may be installed with overhead as well as basement mains. Fig. S-5-7 shows three radiators in a two-pipe down-feed system. The drop supply riser in this arrangement should always be sealed in a manner similar to that for the return riser so as to assure the impossibility of steam passing down the drop supply and into the return line. Sizes of pipes may be established from Tables S-5-1, S-5-2, and S-5-3.

Work Problem S-5-5.

A typical elevation layout of a two-pipe wet-return gravity steam system is shown as Fig. S-5-8, while Fig. S-5-9 shows the dry-return arrangement. These figures are used with application problems S-5-6 and S-5-7.

Work Problems S-5-6 and S-5-7.

In designing a system for a structure, it is necessary that the effect of all valves, fittings and bends in the piping be considered. The following two problems exemplify these design points, The solutions, however, are optional with each student.

Work Problems S-5-8 and S-5-9.

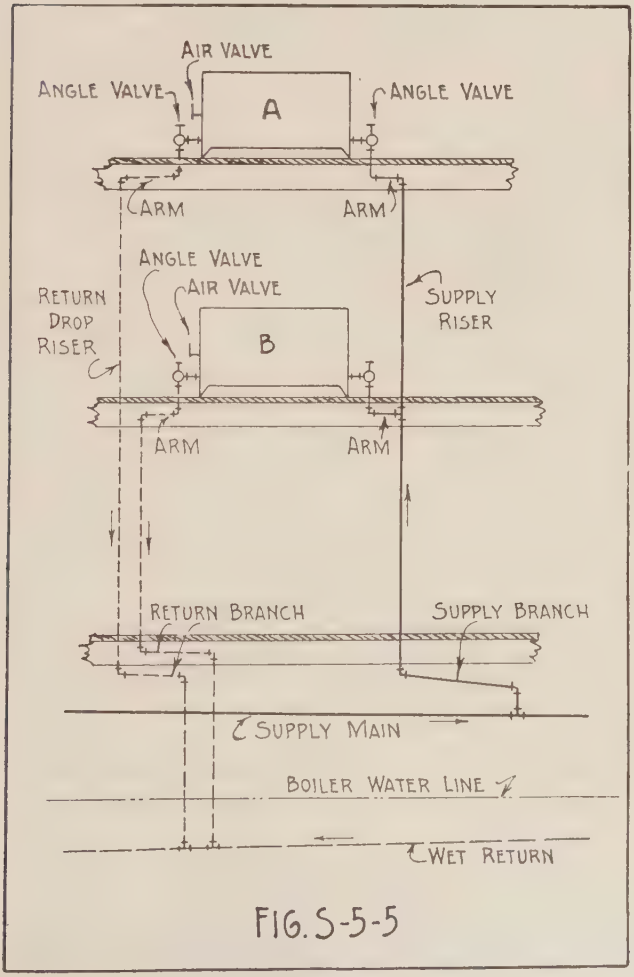


FIG. S-5-5

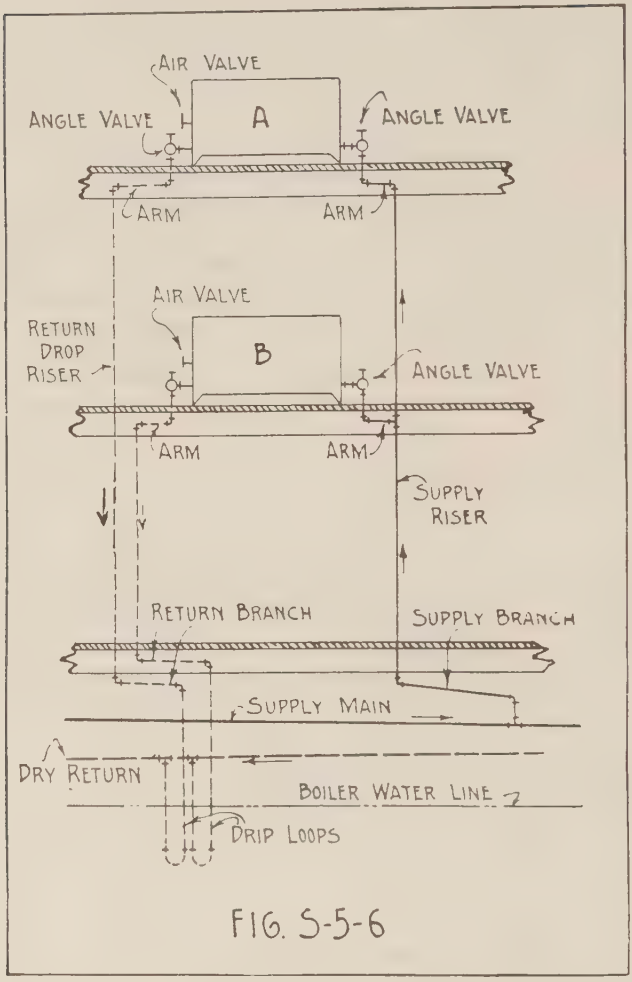


FIG. S-5-6

While the layouts shown in Figs. S-5-1, S-5-2, S-5-8, and S-5-9 show no drips for relieving the main of condensation, such are properly used at various points with these two-pipe systems as were shown and explained in connection with the one-pipe gravity relief system of Lesson S-4 and shown in Figs. S-4-6 and S-4-9. Drip pipe sizes are given in Table S-5-5.

Work Problem S-5-10.

The tables in this lesson for determining pipe sizes are, as explained, based on the same consid-

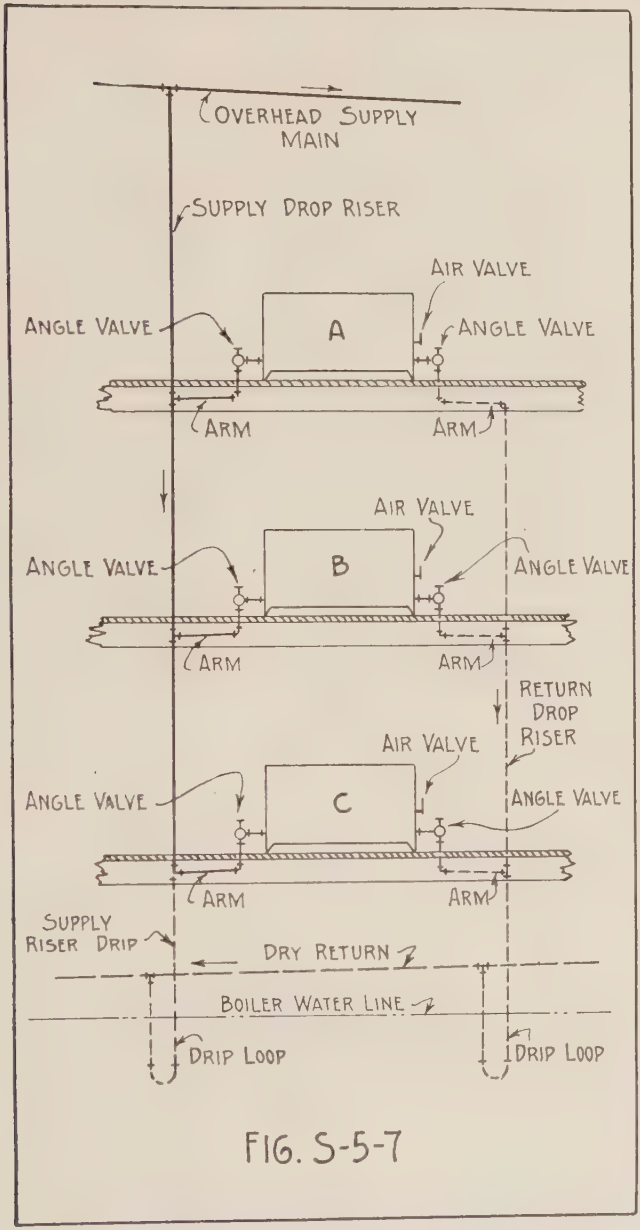


FIG. S-5-7

erations as for those for one-pipe work. A. R. Wolff presented a table for 2 and 5 lbs. low-pressure steam heating from which the sizes and capacities of mains, branches and risers for two-pipe

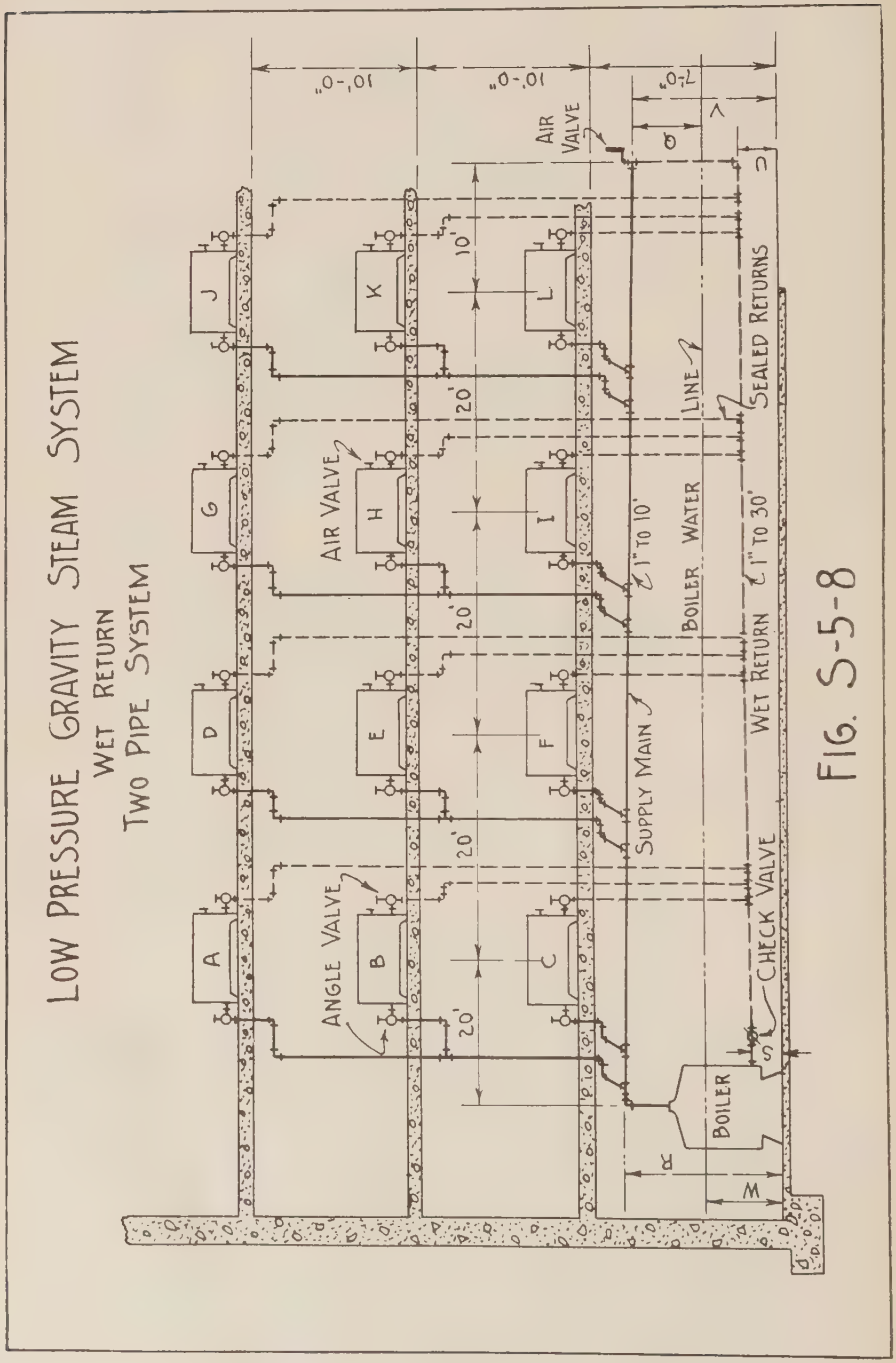

LOW PRESSURE GRAVITY STEAM SYSTEM
WET RETURN
TWO PIPE SYSTEM
A
B
C
D
E
F
G
H
I
J
K
L
ANGLE VALVE
AIR VALVE
AIR VALVE
10'-0"
10'-0"
7'-0"
10'
20'
20'
20'
20'
1" TO 10'
1" TO 30'
SUPPLY MAIN
BOILER WATER LINE
SEALED RETURNS
WET RETURN
CHECK VALVE
BOILER
R
W
S
U
V
Q

FIG. S-5-8

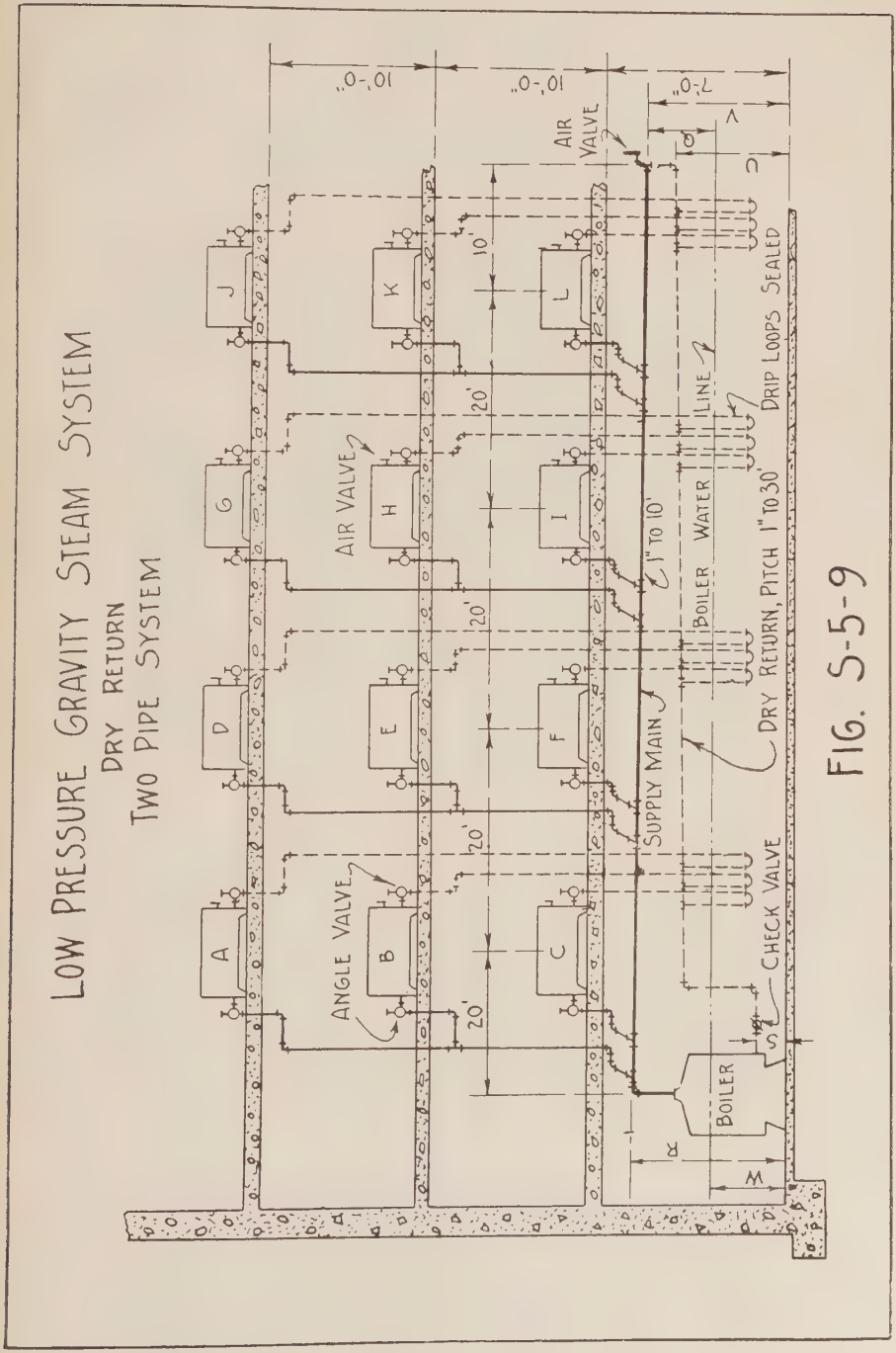

LOW PRESSURE GRAVITY STEAM SYSTEM
DRY RETURN
TWO PIPE SYSTEM
A
B
C
D
E
F
G
H
I
J
K
L
ANGLE VALVE
AIR VALVE
AIR VALVE
SUPPLY MAIN
1" TO 10'
BOILER WATER LINE
DRIP LOOPS SEALED
DRY RETURN, PITCH 1" TO 30'
CHECK VALVE
BOILER
10'-0"
10'-0"
7'-0"
20'
20'
20'
10'

FIG. S-5-9

TABLE S-5-7

TWO PIPE STEAM

SIZES AND CAPACITIES MAINS, BRANCHES, RISERS

(A.R. WOLF)

SUPPLY DIAM. INS.	RETURN DIAM. INS.	2 LB. PRESSURE		5 LB. PRESSURE	
		TOTAL HEAT TRANSMITTED B.T.U. PER HOUR	RADIATING SURFACE SQUARE FEET	TOTAL HEAT TRANSMITTED B.T.U. PER HOUR	RADIATING SURFACE SQUARE FEET
3/4	3/4	5000	20	10000	40
1	3/4	9000	36	15000	60
1 1/4	1	18000	72	30000	120
1 1/2	1 1/4	30000	120	50000	200
2	1 1/2	70000	280	120000	480
2 1/2	2	132000	529	220000	880
3	2 1/2	225000	900	375000	1500
3 1/2	2 1/2	330000	1320	550000	2200
4	3	480000	1920	800000	3200
4 1/2	3	690000	2760	1150000	4600
5	3 1/2	930000	3720	1550000	6200
6	3 1/2	1500000	6000	2500000	10000

FOR RUNS IN EXCESS OF 200 FT, MULTIPLY CAPACITIES BY $\sqrt{\frac{200}{L}}$. L = LENGTH IN FEET.

steam work could be selected for mains as long as 100 ft. Experience with this table, however, has justified its use for runs up to 200 ft. in length, including fittings. The table, in part, is given as Table S-5-7. This table assumes a radiator heat emission of 250 B.T.U. per square foot per hour. Return sizes selected from this table may safely be reduced one pipe size, and, in some instances, with discretion, further reduced.

Work Problems S-5-11, S-5-12.

RETURN-PIPE SIZES

In the consideration of sizes for return-pipe lines, it may be assumed that the same friction-pressure-loss occurs for a given size pipe for steam and water flowing therein. Hence, for the same pressure drop and a given pipe size, the weights

of steam and water will vary as the square roots of their densities. (This will be appreciated by referring to the formula for pressure drop due to steam flowing in a given pipe, see Lesson S-2.) Consequently, if a comparison be made at a temperature of 212°F., water weighs 59.76 lbs. per cubic

TABLE S-5-8

TWO PIPE STEAM

STEAM AND RETURN MAIN CAPACITIES

RUNS OF MODERATE LENGTHS

(JAMES A. DONNELLY)

PIPE SIZE INS.	A STEAM RATING STANDARD DIRECT RADIATION	B WET RETURN ×40	C 2½% STEAM ×20	D 5% STEAM ×13½	E 7½% STEAM ×10	F 10% STEAM ×8	G 15% STEAM ×5.7	H 20% STEAM ×4.4
½	5	200	100	67 5	50	40	27	22
¾	20	800	400	270	200	160	114	88
1	40	1600	800	540	400	320	228	176
1¼	75	3000	1500	1012	750	600	427	330
1½	150	6000	3000	2024	1500	1200	855	660
2	300	12000	6000	4050	3000	2400	1710	1320
2½	500	20000	10000	6750	5000	4000	2850	2200
3	900	36000	18000	12150	9000	7200	5130	3960
3½	1500	60000	30000	20250	15000	12000	8550	6600
4	2000	80000	40000	27000	20000	16000	11400	8800
4½	2800		56000	37800	28000	22400	15060	12320
5	3600			48600	36000	28800	20520	15840
6	6000				60000	48000	34200	26400
7	9000					72000	51300	39600
8	13000						74000	57200
9	18000							79200
10	23000							
12	37000							
14	55000							
16	78000							

In the above table, the maximum capacity of return mains is given for various percentages of steam carried, together with the steam rating of pipes from ½ inch to 16 inches.

Calculations are for a pressure drop of one ounce to 100 feet of straight pipe.

Column A, steam rating in standard direct radiation for piping within buildings for all classes of systems.

Column B, rating for wet return main of a gravity system.

Column C, rating for main return of the Positive Differential System.

Column D, rating for the main return when it is above the water line in a dry return gravity system.

Column E, rating for the branch returns of the Positive Differential System and for the branch returns that are above the water line in a wet return gravity system.

Column F, rating for the branch returns of a dry return gravity system.

Columns G and H, rating for gravity systems where the returns have unusual condensing capacity and for the returns in vacuum systems where jet water is used.

foot and steam weighs 0.0375 lbs. per cubic foot and the relation becomes $\sqrt{\frac{0.0375}{59.76}}$ or $\sqrt{\frac{1}{1600}}$ which reduces to $\frac{1}{40}$ indicating that the capacity of a pipe as a wet return is forty times as great

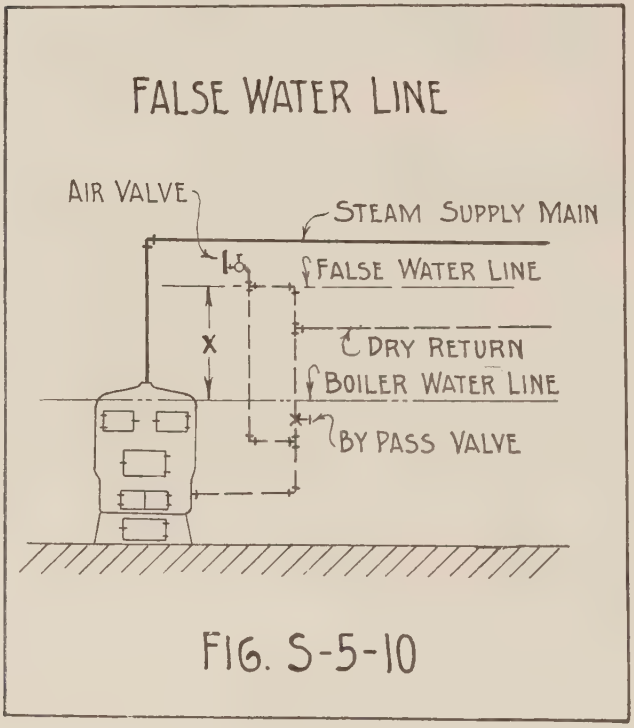


FIG. S-5-10

Work Problem S-5-15.

as it is as a steam main when supplying steam at 212°F.

Work Problem S-5-13.

Dry-return mains carry not only condensation but also varying percentages of steam, depending upon the type of system. Steam thus carried in the return main must be allowed for. James A. Donnelly has estimated such percentages for dif-

ferent systems and prepared a table showing the maximum capacity of return mains when serving as wet returns and as dry returns, carrying various percentages of steam with the condensation. The table is based on a pressure drop of 1 oz. in 100 ft. of straight pipe.

Work Problem S-5-14.

FALSE WATER LINE

Returns that are run above the boiler water-line are dry returns. When it is desirable to change a dry return and run it as a wet return, a false water-line must be established. This is done at the end of the return just before it drops to enter the boiler, as shown in Fig. S-5-10. The new water-line on the converted dry return will then stand at the distance, X, above the boiler water-line, which remains unchanged for other returns that may not have been converted. In this converted wet return the water will stand at a height throughout its length equivalent to the distance of the false water-line above the boiler water-line.

PART S.

STEAM HEATING SYSTEMS

LESSON 6.

Vapor Systems

VAPOR HEATING SYSTEMS.

Vapor is steam at or slightly below atmospheric pressure. Thus, vapor heating systems are, in general, negative pressure steam systems in which no pump is used to produce the partial vacuum. This negative pressure results in the formation of vapor when the pressure is below the atmosphere. Modulation and atmospheric systems are similar to vapor systems except that they lack the vacuum characteristic.

A positive pressure is carried on the boiler, but this pressure may be and, in a properly-installed vapor system, probably seldom exceeds the steam

or vapor pressure in a tea kettle, partially filled with boiling water.

Escaping steam or vapor from a tea kettle rises as it leaves the spout and spreads out in white clouds because such vapor is lighter than the surrounding air. It is not forced upwards but rises because of its relative weight. In a similar manner, vapor given off from the water surface in a boiler in which the temperature is maintained at or near 212° F. (boiling point of water at atmospheric pressure), rises and is guided, by means of pipe lines, to the radiators throughout the structure that is to be warmed. Thus, efficient functioning of a vapor system depends upon the ability to distribute this very low pressure steam throughout the entire system, with the positive assurance that every radiator will receive and continue to receive sufficient volumes of vapor to permit the emission of ample heat in unit time.

As elimination of air and water from the systems of steam heating covered in previous lessons is essential to efficient functioning thereof, so must a vapor system rid itself of these obstacles continually if the vapor is to enter and warm the radiator properly. Various mechanical devices are available to-day for removing air from the system and permitting the return of the condensed water to the boiler by gravity or assuring its return by means of a return trap.

TYPICAL VAPOR HEATING SYSTEM WITHOUT RETURN TRAP

In Fig. S-6-1 there is shown a diagrammatic layout for a typical vapor heating system without a return trap. In addition to the boiler, piping and radiators, the essential features are

(1) a special radiator supply valve for each radiator,

(2) a special trap on the return side of each radiator,

(3) a device for collecting all air eliminated from the radiators with means for expelling same from the system and for holding temporarily condensed water for return to the boiler.

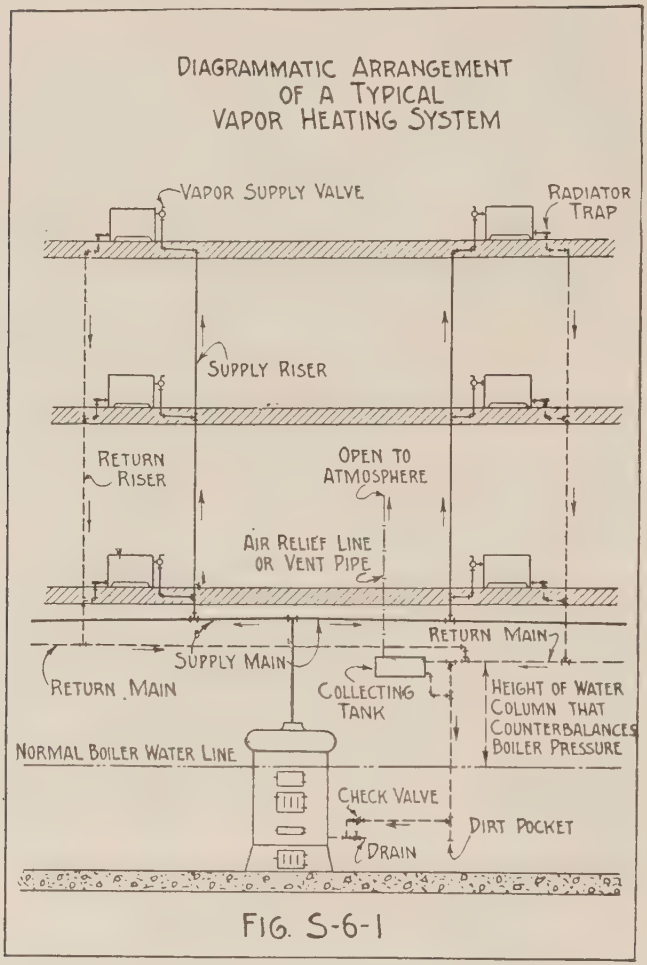


FIG. S-6-1

SPECIAL RADIATOR VALVES

Many firms manufacture supply valves suitable for use on the radiator of a vapor system. These special valves are packless, that is, no packing of any kind is used to assure steam and air tightness. Corrugated metallic bellows take the place of stuffing-box and packing. This metallic bellows expands and contracts as the valve disk is raised or lowered. The material is extremely flexible and strong.

The valve is equipped with a lever handle and so built that the valve may be completely opened or closed with but a part turn of the handle. Some valves open fully on a half turn, others require as much as seven-eighths turn.

Work Problem S-6-1.

Manufacturers of vapor valves supply complete information concerning their product and it is well for every student engaged in the heating business to provide himself with a set of descriptive matter covering the products manufactured for vapor heating work.

In Tables S-6-1, S-6-2, and S-6-3, such data for three manufacturers' products are shown as examples.

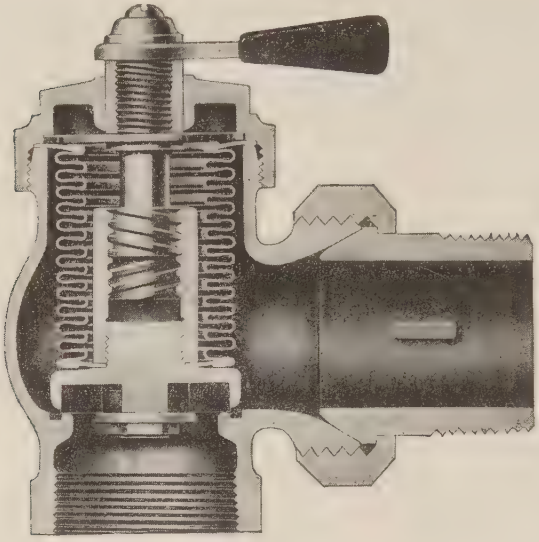
Work Problem S-6-2.

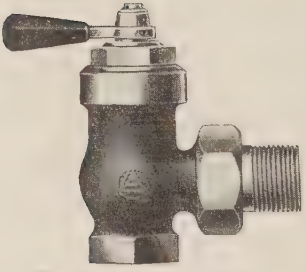
SPECIAL TRAP FOR RADIATORS

Traps used on the radiators of a vapor system are actually air and water relief valves. In order that a radiator supplied with steam or vapor may function properly, it should be kept free of air and the water of condensation should be removed promptly. The type of radiator trap illustrated with Tables S-6-4, S-6-5 and S-6-6 is built by many manufacturers. These traps are of two general types, employing, respectively, the thermostatic and float principle of operation.

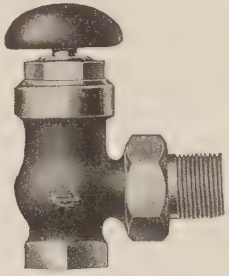
The thermostatic trap is by far the more generally used. The actuating element of a thermostatic trap is a metallic substance having a high expansion coefficient which, when heated, expands and closes the return opening.

Thus air and water are permitted to pass from the radiator into the return, but as soon as the vapor or steam of a higher temperature comes in contact with the metallic element, the element expands, closes the opening, and remains closed until

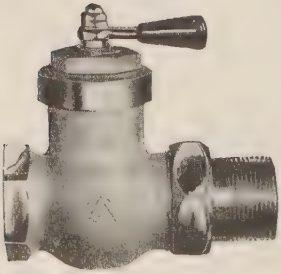




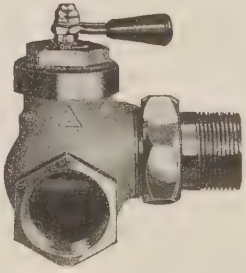
Angle Lever Handle



Angle Round Handle



Globe Type



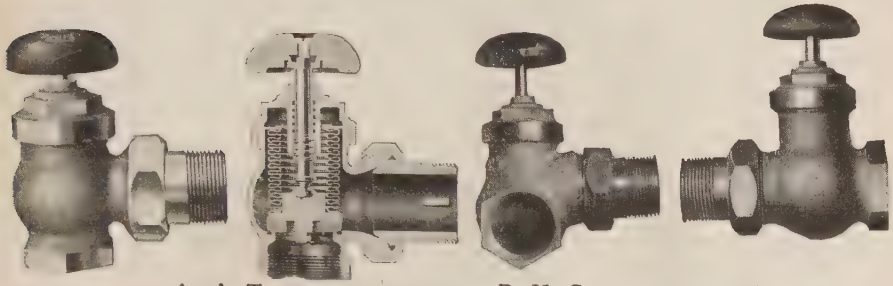
R. H. Corner Type

Courtesy American Radiator Co.

Packless Radiator Valves for Steam and Vapor Heating

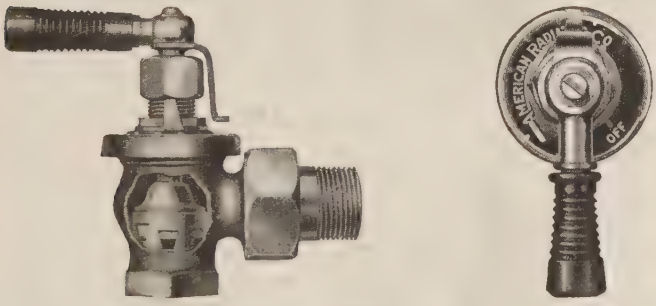
Packless Radiator Valves

Vapor and Steam Heating Systems



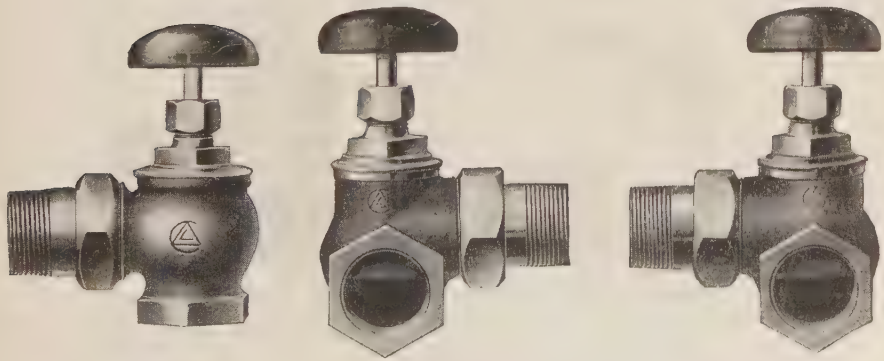
Angle Type R. H. Corner Globe

Multiport Radiator Valve
Vapor Heating



Asbestos Packed Valve

Screw-Stem Steam Radiator Valves



Angle Right-Hand Valve Left-Hand Valve

Courtesy American Radiator Co.

VAPOR VALVES

CAPACITIES — DIMENSIONS

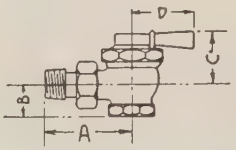


TABLE S-6-1

DUNHAM

SIZE INS.	CAPACITY SQ. FT.	DIMENSIONS		
		A	B	C
1/2	1 - 40	3	1 1/8	1 15/16
3/4	41 - 100	3 1/16	1 1/4	1 15/16
1	101 - 180	3 1/8	1 1/2	2 1/8
1 1/4	181 - 300	3 7/16	1 5/8	2 7/16

TABLE S-6-2

ILLINOIS

SIZE INS.	CAPACITY SQ. FT.	DIMENSIONS	
		A	B
3/4	1 - 100	2 5/8	1 3/8
1	101 - 200	3 1/8	1 9/16
1 1/4	201 - 275	3 1/2	1 3/4
1 1/2	301 - 400	4	2

TABLE S-6-3

TRANE

SIZE INS.	CAPACITY - SQ. FT. PRESSURE DIFFERENCES				DIMENSIONS		
	4 OZ.	8 OZ	1 LB.	2 LB.	A	B	D
1/2	20	28	39	55	2 3/4	1 5/16	2 1/8
3/4	64	90	125	175	2 3/4	1 5/16	2 1/8
1	149	210	294	410	3	1 3/8	2 1/8
1 1/4	375	525	735	1030	3 1/2	1 3/4	2 1/8

sufficient air and water have collected to cool the element enough to cause it to contract and open the outlet into the return.

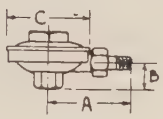
Data on traps of this type as built by three manufacturers are given in Tables S-6-4, S-6-5 and S-6-6 as samples only.

Work Problems S-6-3, S-6-4.

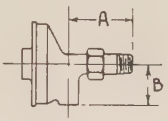
The float mechanism type closes against steam by means of a water seal. Air may rise in an annular space around the float and then flow down into the return, this space being always open except when water of condensation enters the trap and rises high enough to raise the float. Through the center of the float there is a tube to which is attached a plate. When the float has risen to a proper point, this plate seats a valve against the

RADIATOR TRAPS

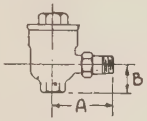
CAPACITIES — DIMENSIONS



DUNHAM



ILLINOIS



TRANE

TABLE S-6-4

DUNHAM

No.	SIZE INS	CAPACITY SQ.FT. DIRECT	DIMENSIONS		
			A	B	C
1	1/2	100	3 1/8	1 1/8	2 3/8
2	1/2	350	3 3/4	1 1/4	3 15/16
3	3/4	450	3 7/8	1 1/4	3 15/16
4	3/4	1500	2 3/4	2 3/16	5 7/8

TABLE S-6-5

ILLINOIS

No.	SIZE INS.	CAPACITY SQ.FT. DIRECT	DIMENSIONS	
			A	B
1	1/2	75	2 3/8	1 5/8
2	1/2	200	2 1/2	1 3/4
3	3/4	500	2 3/4	2 7/16
4	1	1500	1 3/4	3 1/4

TABLE S-6-6

TRANE

No.	SIZE INS.	CAPACITY - SQ.FT. DIRECT				DIMENSIONS	
		PRESSURE DIFFERENCE					
		4 OZ.	8 OZ.	1 LB	2 LB.	A	B
B-2	1/2	125	175	245	344	3 1/4	1 7/16
B-3	3/4	375	525	735	1030	3 1/4	1 7/16
B-4	1	750	1050	1700	2200	3 9/16	1 23/32

air outlet in the top and simultaneously lifts a valve in the bottom, permitting the water to flow out until the float again assumes its low position.

Radiators having the supply connection at the top are preferred for vapor systems since this puts the supply valve in the most accessible position.

PRINCIPLE OF VAPOR SYSTEM

In the U tube A of Fig. S-6-2, it is assumed that atmospheric pressure is acting on the surface of water in each leg of the tube. Hence, the water level is the same in both legs.

A column of water 1 ft. high having a transverse area of 1 sq. in. exerts a pressure of practically 0.434 lb. per square inch. Thus, the equivalent static head of water for a pressure of 2 lbs. per square inch will be $2 \div 0.434 = 4.6$ ft.

If a uniform pressure of 2 lb. per square inch be exerted on the water surface in the left leg of the U-tube B, Fig. S-6-2, the water would be forced into the right leg until the vertical difference in the height of the two surfaces, represented by X, became 4.6 ft. (as per calculations above.)

If the pressure exerted on the water surface of the left leg be reduced to 1 lb. per square inch, the height of water column Y, U tube C, Fig. S-6-2, will be reduced to 2.3 ft. If the pressure be still further reduced to 4 oz. per square inch or ¼ lb., the height of balancing column Z, U tube D, Fig. S-6-2, will suffer a corresponding reduction, while for 1 oz. pressure the height W of U tube E, Fig. S-6-2, indicates that for an extremely low pressure above atmospheric requires but a slight hydrostatic head to balance it.

If, now, the U tube be replaced by a boiler, representing one leg of the tube, and a small vessel, open to the atmosphere, representing the other leg of the U tube, see A, Fig. S-6-3, and the bottoms of the vessels be connected through a pipe line, a difference in water levels will exist and this difference will be governed by the pressure in the boiler.

Work Problem S-6-5.

The introduction of a steam main, radiator and return piping connected as shown at B, Fig. S-6-3, is all that is required to produce a vapor plant diagram with radiator traps and gravity return. A study of this diagram in connection with Fig. S-6-1 should make perfectly clear the operating principle of such a vapor plant.

In a vapor system, a positive pressure from 1 oz. to 1 lb. is usually carried on the boiler. The pressure in the return line is higher than that of the surrounding atmosphere, due to the column of water maintained in the return. The pressure of this static head of water which counter-balances the pressure carried in the boiler and which exists between an opening to the atmosphere and the boiler makes it possible to air-vent the system automatically, while, at the same time, carrying a positive pressure on the boiler. Thus, for any given positive pressure desired on the boiler, it is necessary that the lowest part of the return, where an air vent is located, and the lowest radiator be high enough above the normal boiler water-line to permit the necessary static head. Thus, the water may back up in the return and establish this head, all air and water from radiators being carried through a dry return to a collecting tank, at which point venting of the entire system occurs.

For practical reasons, the collecting tank is located higher above the boiler water-line than theoretically required. Manufacturers who build equipment especially for vapor plants always specify this distance for their particular apparatus. The student should acquaint himself with such installation details for the various trade systems with which he may come in contract. Most manufacturers are glad to supply serious-minded enquirers with copies of their literature. In making such a request, however, the enclosure of return postage is a courtesy that will be appreciated.

Work Problem S-6-6.

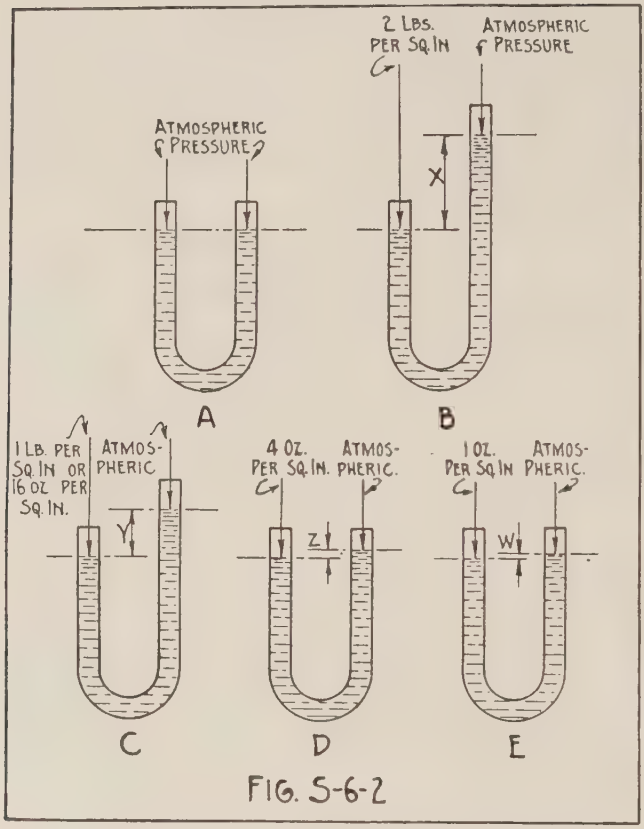
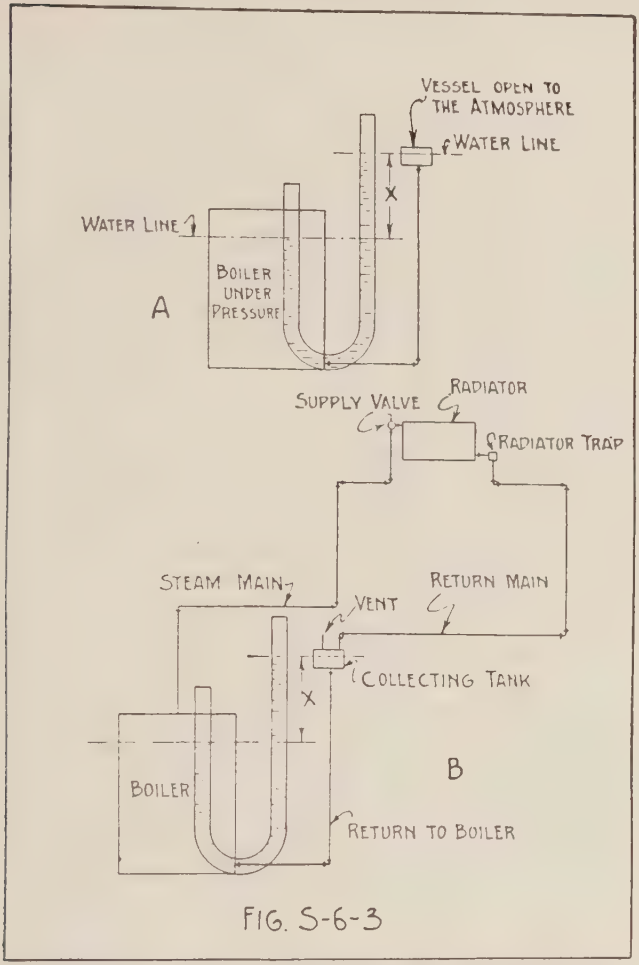


Fig. S-6-2. U-Tubes Illustrating Balanced Pressure Conditions

PIPE SIZING FOR VAPOR SYSTEM WITHOUT RETURN TRAP

While it is difficult to lay down any hard and fast rules for sizing pipes, yet Tables S-6-7 to S-6-11 inclusive may be expected to produce satisfactory designs. These tables and others that follow will likely vary slightly from other similar tables. The student should ever realize that judgment and experience must be given due consideration in the design of any job and hence all tables should be considered elastic.



Diagrammatic Layout for a Simple Vapor Heating System without Direct Return Trap

Students who have completed the work up to this point have had sufficient practice in sizing pipes to permit the omission of radiator group layouts and for this reason such as have been included with previous lessons are not included herewith.

Fig. S-6-4 illustrates a vapor heating system installed in phantom building.

Work Problem S-6-7.

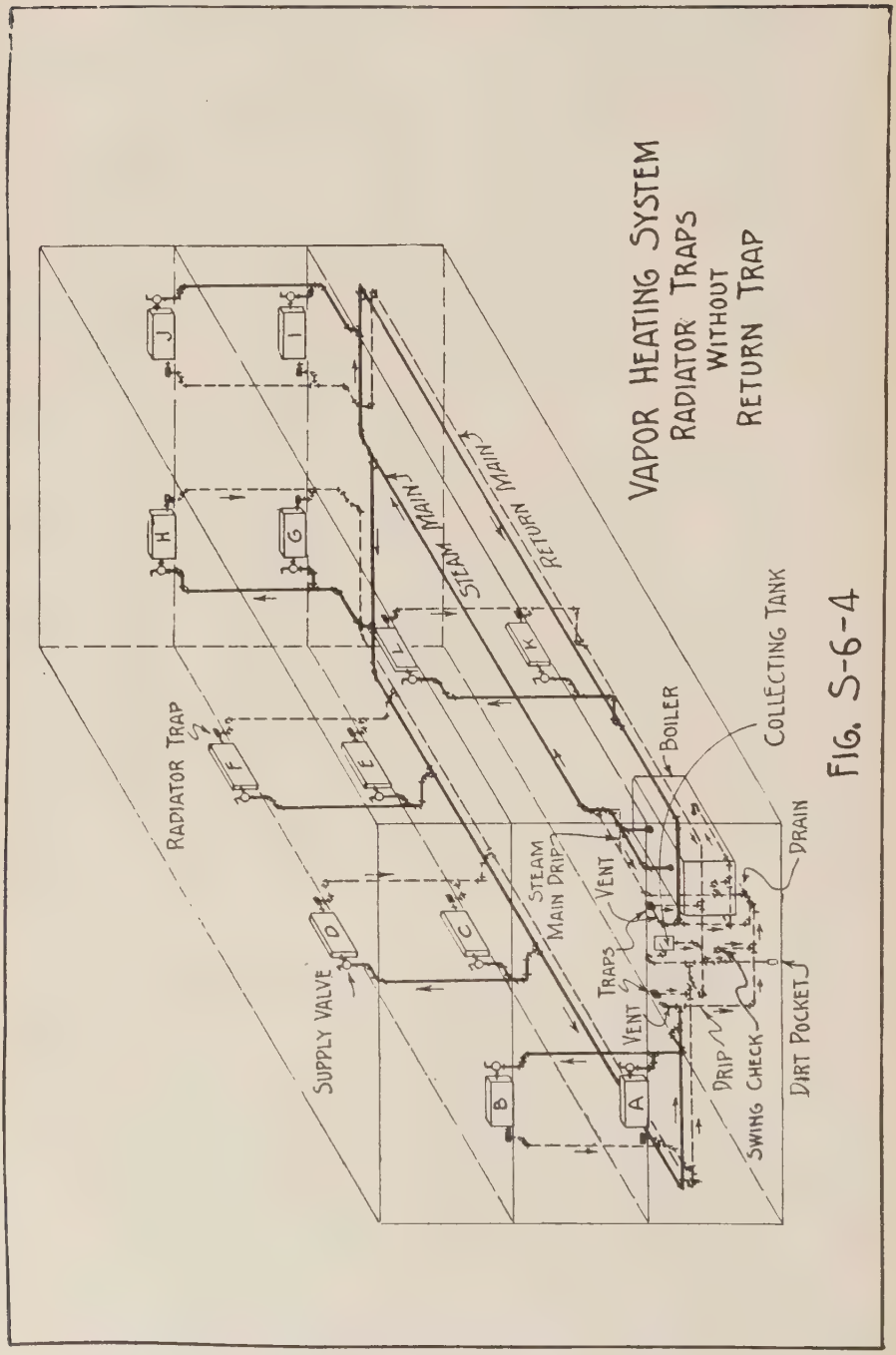

VAPOR HEATING SYSTEM
RADIATOR TRAPS
WITHOUT
RETURN TRAP
STEAM MAIN
RETURN MAIN
RADIATOR TRAP
SUPPLY VALVE
STEAM MAIN DRIP
TRAPS
VENT
VENT
DRIP
SWING CHECK
DIRT POCKET
BOILER
COLLECTING TANK
DRAIN
A
B
C
D
E
F
G
H
I
J
K
L

FIG. S-6-4

TABLE S-6-7

RADIATOR CONNECTIONS

HOT WATER TYPE RADIATOR - TOP INLET

SQUARE FEET RADIATION DIRECT	SUPPLY			RETURN		
	INLET VALVE SIZE INS.	VERTICAL PIPE TO INLET VALVE INS.	HORIZONTAL RUNOUT TO RISER INS.	TRAP NO.	VERTICAL PIPE TO TRAP INS.	HORIZONTAL RUNOUT TO RETURN RISER INS.
1 - 40	1/2	1/2	3/4	1	1/2	3/4
41 - 80	3/4	3/4	1	1	1/2	3/4
81 - 100	3/4	3/4	1 1/4	1	1/2	3/4
101 - 140	1	1	1 1/4	2	1/2	3/4
141 - 180	1	1	1 1/2	2	1/2	3/4

WITHOUT RETURN TRAP

TABLE S-6-8

RISERS

EQUIVALENT LENGTH FEET	SUPPLY					RETURN
	3/4"	1"	1 1/4"	1 1/2"	2"	3/4"
100	40	80	160	250	400	500
200	25	55	115	175	320	320
400	20	40	80	125	240	250

WITHOUT RETURN TRAP

VAPOR HEATING SYSTEM WITH RETURN TRAP

The function of a return trap in a heating system is to return water to the boiler under conditions that prevent or interfere with assured gravity return.

With a heating system such as has been described in the foregoing part of this lesson or, in fact, with any system equipped with radiator traps, there is liable to be two pressures on the system, especially if the radiator traps function properly without leakage. While such different pressures may be

TABLE S-6-9
SUPPLY MAINS
SQUARE FEET · DIRECT RADIATION

PIPE SIZE INS.	LENGTH IN FEET			
	200	300	400	500
2	320	282	248	218
2½	560	456	400	352
3	1000	810	710	625
3½	1500	1180	1035	910
4	2000	1640	1440	1270
4½	2680	2180	1920	1690
5	3600	2940	2580	2260
6	5780	4700	4130	3640

WITHOUT RETURN TRAP

TABLE S-6-10
RETURN MAINS

PIPE SIZE INS.	CAPACITY SQ. FT.
1	300
1¼	600
1½	1800
2	3000
2½	5500

WITHOUT RETURN TRAP

TABLE S-6-11
SUPPLY DRIPS

PIPE SIZE INS.	CAPACITY SQ. FT.
1¼	1000
1½	2000
2	4000
2½	6000

WITHOUT RETURN TRAP

slight, yet, under certain conditions of operation the difference in pressure on the supply side and on the return side may be sufficient to prevent the proper return of the water of condensation to the boiler by gravity.

Fig. S-6-5 illustrates a simple vapor heating system with return trap. Suppose steam is being generated in the boiler faster than it is being condensed in the radiators and piping of the system. Steam will then fill the main, and all piping and radiators from the boiler to the radiator trap.

TABLE S-6-12

RADIATOR CONNECTIONS

HOT WATER TYPE RADIATOR - TOP INLET

SQUARE FEET RADIATION DIRECT	SUPPLY			RETURN		
	INLET VALVE SIZE INS.	VERTICAL PIPE TO INLET VALVE INS.	HORIZONTAL RUNOUT TO RISER INS.	TRAP NO.	VERTICAL PIPE TO TRAP INS.	HORIZONTAL RUNOUT TO RETURN RISER INS.
1 - 40	1/2	1/2	3/4	1	1/2	3/4
41 - 100	3/4	3/4	1	1	1/2	3/4
101 - 180	1	1	1 1/4	2	1/2	3/4
181 - 300	1 1/4	1 1/4	1 1/2	2	1/2	3/4

WITH RETURN TRAP

TABLE S-6-13

RISERS

EQUIVALENT LENGTH FEET	SUPPLY							RETURN	
	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"	3/4"	1"
200	45	90	190	290	570	930	1650	600	1200
400	30	60	136	200	410	670	1170	430	850
600	25	50	110	165	330	530	940	340	670
1000	20	40	85	130	250	410	730	260	530

WITH RETURN TRAP

The air vent valve installed at the end and low point of the return main permits water of condensation to flow downwards, through the check valve C_1 and up into the return trap. This return trap, being connected through a vent opening into the return line, places the trap under the same pressure as exists in the return main.

As water passes through check valve C_1 and rises into the body of the return trap, the operating mechanism therein opens the connection to the steam line and closes the vent connection. The same pressure will then exist in the return trap as exists in the boiler. This will permit the water collected in the return trap to drain by gravity

TABLE S-6-14
SUPPLY MAINS
SQUARE FEET DIRECT RADIATION

PIPE SIZE INS.	LENGTH IN FEET					
	100	200	300	400	500	600
2	670	570	470	410	360	330
2½	1090	930	760	670	590	530
3	1930	1650	1340	1170	1030	940
3½	2810	2400	1950	1710	1510	1370
4	3900	3340	2720	2380	2100	1900
4½	5220	4460	3630	3180	2800	2550
5	7000	5950	4850	4260	3740	3400
6	11200	9550	7780	6830	6000	5460

WITH RETURN TRAP

TABLE S-6-15
RETURN MAINS

PIPE SIZE INS	SQUARE FEET	
	UNDER 400 FT	OVER 400 FT.
1	400	300
1¼	1400	1000
1½	2700	1700
2	5500	3400
2½	9000	5500
3	16000	10000
3½	23000	14000
4	32000	20000

WITH RETURN TRAP

TABLE S-6-16
SUPPLY DRIPS

PIPE SIZE INS	CAPACITY SQ. FT.
1¼	1400
1½	2700
2	5500
2½	9000
3	16000
3½	23000
4	32000

WITH RETURN TRAP

through check valve C_2 into the boiler, since the water in the trap is under a greater hydrostatic head than the water in the boiler.

When the return trap has been emptied sufficiently, the trap mechanism operates to close the valve to the steam line and open the vent valve. Water will then again flow into the return trap through check valve C_1 and the operation of returning it to the boiler be repeated.

The position of the return trap above the water line in the boiler, that is the value of distance X, is most important. It is dependent upon boiler operating pressure and the total radiating or condensing surface of the system. Manufacturers who build return traps always specify this distance for their particular apparatus.

Work Problem S-6-8.

PIPE SIZING FOR VAPOR SYSTEM WITH A RETURN TRAP

With the same admonition concerning pipe sizing tables as was given above, Tables S-6-12 to S-6-16 are presented. The student should note

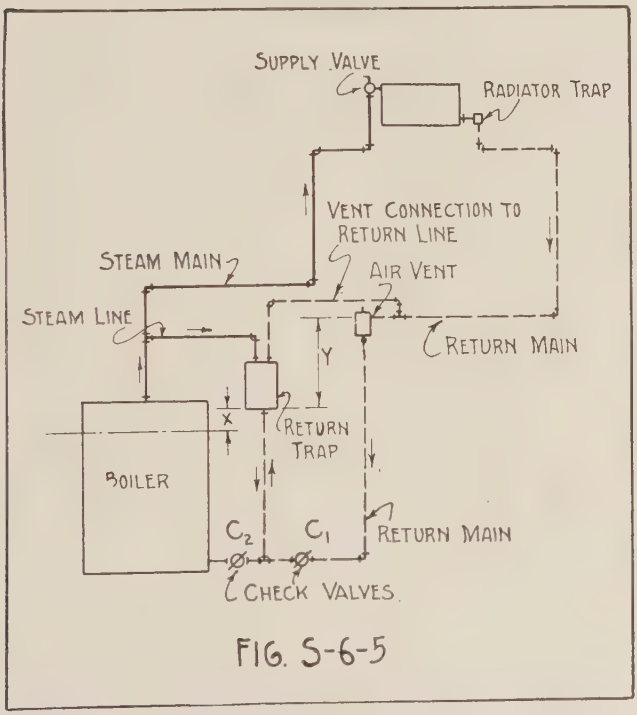


Fig. S-6-5. Diagrammatic Layout for a Simple Vapor Heating System with Direct Return Trap

that the design of a system using a direct return trap will differ from one in which only radiator traps were installed.

Work Problems S-6-9, S-6-10.

PART S.

STEAM HEATING SYSTEMS

LESSON 7.

Installation Details

STEAM HEATING SYSTEMS.

ELEVATION OF WATER IN RETURNS.

The effect of pipe fittings, valves, etc., upon steam flow was covered in Lesson S-3. Friction due to pipes, valves, etc., causes a loss of pressure between the boiler and points along the line. Therefore, as the steam travels away from the boiler, its pressure becomes less than at the boiler.

The point of lowest pressure in the main is at the end. The return main connects this point of lowest pressure directly with the boiler and, since water transmits pressure equally and undiminished in all directions, the pressure in the return main at this far point from the boiler will be the same as that in the boiler.

The velocity of flow of the water in the return main is relatively low since its volume is only one seventeen-hundredth of the volume of the steam from which it is condensed. Since the steam pressure at the end and at points along the steam main is lower than at the boiler, the water in the return main at the end where it is connected with the steam main, will rise to the level or height above the boiler water line so as to establish a static head equal to the pressure difference between that in the boiler and that at the end of the main or at the point in question.

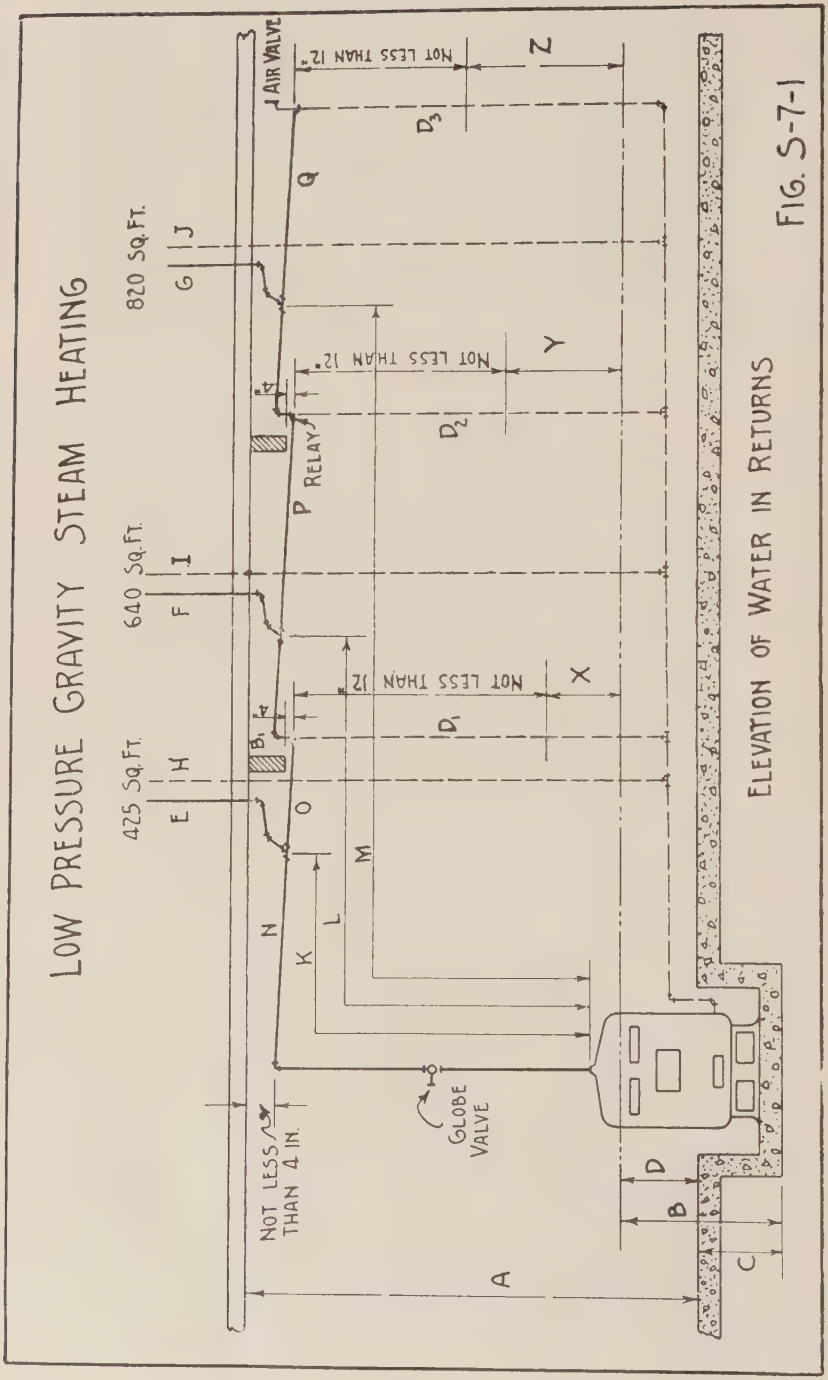
SMALL MAINS THE CAUSE OF FLOODING

Where the system has been poorly designed, the difference in pressure between these two points may be sufficient to cause a flooding of the steam main at the far end. This is most likely to be the case where small mains are used with consequent excessive drop in pressure, requiring that the boiler be set in a pit in order to assure proper allowance for the elevations of the water at different points. Greater depths are at times demanded so as to provide for non-uniform grades for the mains and to avoid beams or girders.

Fig. S-7-1 shows a typical low-pressure wet-return gravity steam layout where relays are required. The use of these "step-ups" necessitates the use of extra fittings. These extra fittings increase the resistance to steam flow and consequently add to the pressure loss in the system. Each relay should be drained as shown in Fig. S-7-1 or as per Fig. S-7-2.

The elevations of the water above boiler water line in the three drips designated as D_1, D_2, D_3, Fig. S-7-1, are indicated by the letters X, Y, and Z. It should be observed that these heights differ, the greatest being in the drip farthest from the boiler.

In practice, it is advisable to consider carefully all problems of steam distribution in which conditions similar to these illustrated in Fig. S-7-1 are met.


LOW PRESSURE GRAVITY STEAM HEATING
ELEVATION OF WATER IN RETURNS
FIG. S-7-1
AIR VALVE
NOT LESS THAN 12"
RELAY
GLOBE VALVE
NOT LESS THAN 4 IN.
820 Sq.Ft.
640 Sq.Ft.
425 Sq.Ft.
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
X
Y
Z

DETERMINING THE DEPTH OF BOILER PIT

The following solution and explanation should enable the student to investigate properly and determine when a boiler pit is required and, if required, the depth of such. Reference to Fig. S-7-1 will identify the following notations and data.

A = basement floor to ceiling = 7 ft. 6 in.
B = height of boiler waterline = 60¾ in.
C = to be determined.
D = height of boiler waterline above floor = (B-C).
E = riser to point where 425 sq. ft. radiation is taken off = 2 in.
F = riser to point where 640 sq. ft. radiation is taken off = 2½ in.
G = riser to point where 820 sq. ft. radiation is taken off = 2½ in.
H = return from 425 sq. ft. radiation = 1½ in.
I = return from 640 sq. ft. radiation = 2 in.
J = return from 820 sq. ft. radiation = 2 in.
K = actual length to first take-off = 60 ft.
L = actual length to second take-off = 125 ft.
M = actual length to third take-off = 250 ft.
N = size of main to first take-off (to be determined).
O = size of main to second take-off (to be determined).
P = size of main to drop take-off (to be determined).
Q = size of main to drop (to be determined).
X = elevation of water in first drip connection (to be determined).
Y = elevation of water in second drip connection (to be determined).
Z = elevation of water at end of run drip (to be determined).
Steam pressure at boiler = 5.3 lbs. gage.
B_1 = 18 inches.

The first step is to establish the size of pipe N. Steam to supply all radiation flows through this section.

The total radiation is equal to 1885 sq. ft. On the basis of an assumed pressure loss of 1.5 oz.

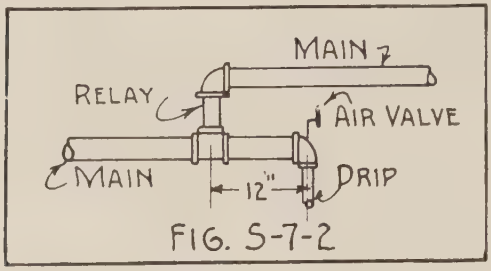


Fig. S-7-2. Method of Draining Relay

per 100 ft. pipe to this first take-off, by Table S-3-2, the size of pipe N will be 4-in. If a slightly greater loss be allowed, a 3½-in. pipe may be used. For the demonstration of the principle here embodied this size will be selected.

The equivalent length of run from the boiler to the first take-off should be checked as follows:

Actual length, K	=	60 ft.
Equivalent lengths		
Boiler outlet (consider equal to one globe valve)	=	39 ft.
Globe valve in line	=	39 ft.
One elbow	=	12 ft.
One tee	=	31 ft.
Total equivalent length	=	181 ft.

If it be assumed that each square foot of radiation will condense 0.25 lbs. of steam per hour (the actual condensation depends upon the kind of radiating surface) and on this basis estimate the quantity of steam flowing per minute, the value obtained is

0.25 (lbs.) $\times$ 1885 (sq. ft.) $\div$ 60 (min.) = 7.8 lbs. per min.

The pressure drop from boiler to first take-off for the conditions stated, as may be computed by the form outlined in Lesson S-2, is 0.086 lbs. when 7.8 lbs. of steam is flowing per minute, with an initial pressure of 5.3 lbs. per sq. in. at the boiler. The pressure at the first take-off, or foot of riser E, will then be

5.3 — 0.086 = 5.214 lbs. per square inch gage.

A similar procedure is carried through for section O, Fig. S-7-1, of steam main. This section must supply steam for 1460 sq. ft. of radiation. By Table S-3-2, and allowing a slightly greater pressure drop than in section N, a 3-in. pipe may be selected as suitable. The equivalent length of this run will be as follows:

Actual length = L — K; 125 ft. — 60 ft.	= 65 ft.
Equivalent lengths	
2—standard elbows (90°)	= 20 ft.
1—tee	= 26 ft.
Total equivalent length (between first and second take-off)	111 ft.

The quantity of steam to be supplied per minute through this section will be 0.25 (lbs.) × 1460 (sq. ft.) ÷ 60 (min.) = 6.1 lbs. The pressure drop between the two ends of this section O will then be (calculated as explained in Lesson S-2) 0.089 lbs.

The pressure at foot of riser F will therefore be 5.214 — 0.089 = 5.125 lbs. per sq. in. gage.

Similar procedure for section P is carried through as follows:

This section must supply steam for 820 sq. ft. By Table S-3-2, a 2½ in. pipe may be selected. The equivalent length of this run will be:

Actual length = M — N;	
250 ft. — 125 ft.	= 125 ft.
Equivalent lengths	
2—standard elbows (90°)	= 14 ft.
1—tee	= 20 ft.
Total equivalent length (between second and third take-off)	159 ft.

The quantity of steam to be supplied per minute through this section will be
0.25 (lbs.) × 820 (sq. ft.) ÷ 60 = 3.42 lbs.

The pressure drop between the two ends of this section P will then be (calculated as explained in Lesson S-2) 0.085 lbs.

The pressure at foot of riser G will then be
5.125 — 0.085 = 5.040 lbs. per sq. in. gage.

A cubic foot of water at 212° F. weighs 59.76 lbs. A column of water having an area of 1 sq. in. and height of 1 ft. will weigh 59.76 ÷ 144 = 0.415 lbs. The head in inches equivalent to 1 lb. pressure will be 1 ÷ 0.415 × 12 (in.) = 28.92 in.

Thus the heads of water required at X, Y, and Z to offset the pressure loss in the main up to where the risers E, F and G are taken off will be:

At X, 0.089 (lbs.) × 28.92 (in.) = 2.57 in. head.
Y, (0.089 + 0.085) × 28.92 (in.) = 5.02 in. head.
Z, (0.089 + 0.085 + 0.085) × 28.92 (in.) = 7.48 in. head.

DEPTH OF PIT

With the necessary data at hand, calculations to determine depth of pit, if needed, may be made. In so doing, it should be borne in mind that the depth must not only provide for the maximum elevation of water in the drops, but also for the clearance required to pass beams, the pitch demanded to maintain proper grade plus all other clearances that may be required. Separate tabulations will be made for each of the points since any one of them may govern.

Conditions at X

Beam = B_1	= 18 in.
To center of tee	= 4 in.
Minimum allowance	= 12 in.
Elevation (X)	= 2.57 in.
Water line	= 60.75 in.
Total	= 97.32 in.
Height of Basement	= 90.00 in.
Depth pit C	= 7.32 in.

Conditions at Y

Beam = B_1	= 18 in.
To center of tee	= 4 in.
Minimum allowance	= 12 in.
Elevation (Y)	= 5.02 in.
Water line	= 60.75 in.
Total	= 99.77 in.
Height of Basement	= 90.00 in.
Depth of pit C	= 9.77 in.

Conditions at Z

Clearance of relay	= 4 in.
Grade of pipe	= 2 in.
Minimum allowance	= 12 in.
Elevation (Z)	= 7.48 in.
Water line	= 60.75 in.
Total	= 86.23 in.
Height of Basement	= 90.00 in.

Hence, so far as conditions at Z are concerned, no pit is necessary. The boiler could be set on the basement floor. The governing condition is at Y, calculations indicating that the boiler must be set at least 10 inches below the basement floor. A pit 12 inches deep should be specified.

Work Problems S-7-1, S-7-2, S-7-3

The design of a system of steam heating embodies considerably more than establishing radiator sizes and proportioning pipe lines. Three fundamental requirements must be observed when designing and installing a system of steam piping. They are:

1. That provision be made for expansion.
2. That proper means for draining condensation from the steam main and other parts of the system and returning same to the boiler be provided.
3. That due regard be given to the arrangement and use of pipes of proper size so that pressure drop will not be excessive.

In preceding lessons proportioning of pipes was covered for the different systems described. While it is possible to lay down certain rules, the use of which will go far toward producing a correct design, yet every student should realize that practically every design and installation presents its own individual peculiarities. The true student, therefore, will accept principles as fundamentals and will apply principles as covered in a work of this kind according to his judgment.

EXPANSION

When a system of piping is installed, it is cold as compared with conditions to which it is subjected during operation. When metal is heated, it expands.

A steam pipe, 100 ft. long, installed at a temperature of 60°F. will be somewhat longer when filled with steam. The heat in the steam causes the pipe to lengthen, demanding installation in such a way as will protect it from breakage when in use. Provision for linear expansion of pipes due to temperature changes must be made. Otherwise the design will be faulty.

Low-pressure heating systems are subjected to temperature differences from 150° to 180° and higher. Unless compensating provision be made, excessive and often serious strains on the pipe and fittings occur. A rough rule for low-pressure piping is to allow 1 in. expansion for every 100 ft. of pipe. By so doing, "bowing" of the line and enormous strains on fittings and flanges are guarded against.

When a system of piping is being designed, a point in the line should be selected and the pipe assumed to be fixed or anchored at that point. A comprehensive study should then be made to determine the amount and direction of the expansion. In this manner, the elongation of all parts can be cared for properly.

Expansion in a steam heating system may be absorbed in two general ways:

(a) by the turning of some of the threaded joints;

(b) by the bending of the pipes.

The first method is preferred, by far, to the second, and should always be employed where the expansion is liable to be appreciable. While the second method may be permissible for conditions where expansion is slight, there is always the danger of sagging or bowing pipes, accentuating the undesirable possibility of reduced area. The illustrations in Fig. S-7-3 show how improperly-graded or installed pipes form pockets and it may be appreciated how a further sagging, with consequent greater pocketing due to failure to consider expansion, can aggravate the trouble and not only cause hammering and pounding throughout the system but possible severe damage.

When pipe runs are very long, as in power plant work, with consequent increased temperature differences, special slip-joints or expansion fittings may have to be used, but they should be avoided in heating work whenever possible.

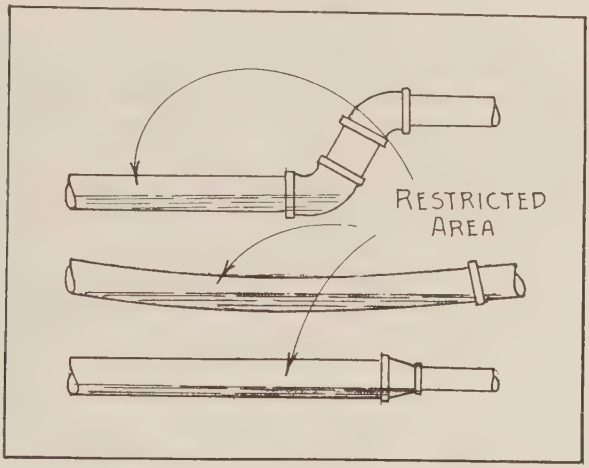


Fig. S-7-3. Improperly Graded or Installed Pipes Form Water Pockets

DRAINAGE

All pipes carrying saturated steam contain some proportion of water. In connection with some of the systems covered in preceding lessons, it was explained that certain of the pipes carried water due to condensation in the pipe itself as well as from other pipes and from radiators. It is important, therefore, that proper conditions of flow and drainage exist. In horizontal runs, it is considered highly advisable that the water flow in the same direction as the steam. In such systems as previously covered, a pitch of at least 1 in. to 10 ft. was specified for the supply lines, the pipe being pitched in the direction of flow.

For conditions where condensation must be drained against the flow of the steam as in radiator runouts for single-pipe systems or in a branch to a riser, a still greater pitch should be provided and relatively larger pipes used in order to assure a low

steam velocity. Drip connections must always be provided where any pocket or low point might permit water to accumulate.

PIPING DETAILS

Construction details and the design of the piping system is often considered by many so-called heating engineers as rather an unimportant feature of the heating system. This is unfortunate for, regardless of the merits of the apparatus and equipment which may be used, they will not compensate for improper design. Heating is a real science and when appreciated as such, the many heating troubles caused by guesswork in design or installation are eliminated. One authority pointedly has remarked concerning the piping system that "it is just as important as the circulating medium (the veins and arteries) is in the human system." Hence, carefully-considered and prepared piping layouts and details return dividends many times in satisfactory and rewarded service.

Expansion in horizontal mains customarily is considered by assuming the main as anchored at the boiler and permitted to expand freely from that point. Thus the movement of any point along the length of pipe will depend upon the distance of the point from the fixed or anchored point.

Work Problem S-7-4

Detail A and B of Fig. S-7-4 show methods of connecting branches to the main whereby provision is made for movement due to expansion. As the main moves longitudinally, the threaded joints a, a, turn slightly. While the method at A is accepted, detail B is to be preferred to it since a 45-degree elbow offers considerably less resistance to the flow of steam than the 90-degree elbow. Expansion also occurs in the horizontal branch. This expansion is usually cared for by permitting the riser to spring slightly and, since a branch is seldom over 10 ft. long, the spring required is not sufficient to be at all dangerous. Such a piping arrangement, as

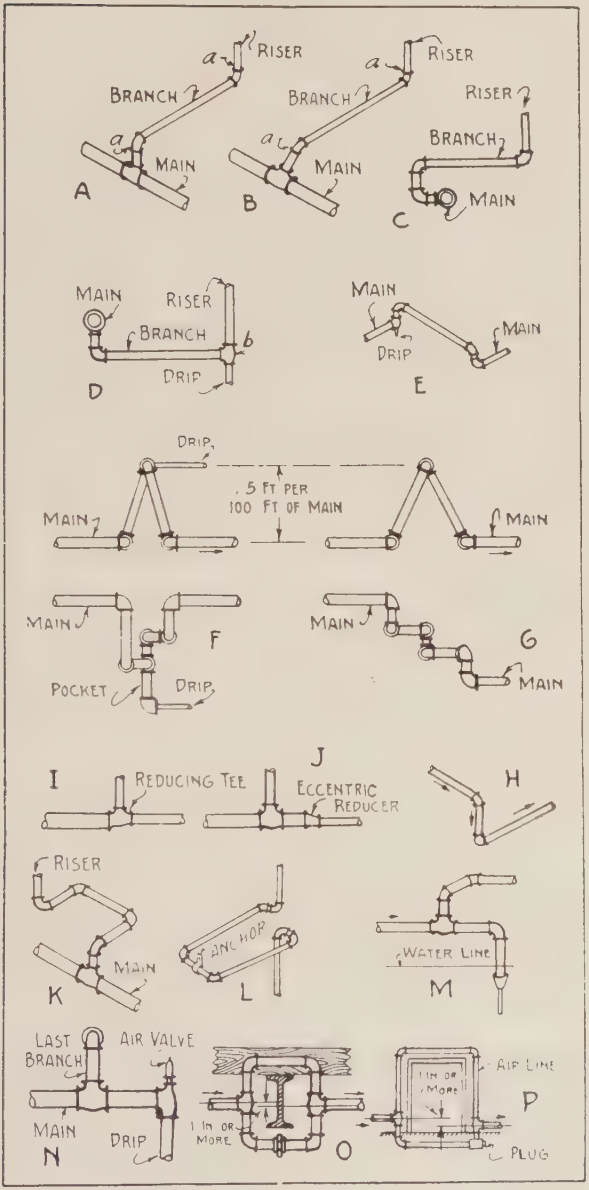


Fig. S-7-4. Piping Details

shown in detail B, can usually be expected to care for expansion at these points in buildings as high as four stories.

Work Problem S-7-5

When the main, either vertical or horizontal, is long, that is, 100 ft. or more, an expansion joint must be provided for each 100 ft. or fraction thereof. Detail C of Fig. S-7-4 shows a method of connecting the branch to the main to provide for greater expansion.

Work Problem S-7-6

Detail D, Fig. S-7-4, illustrates the method of piping where a branch is taken from the bottom of the main as in the case of the one-pipe relief system covered in Lesson S-4. The objectionable feature to be observed in this arrangement is that if the water level rises in the return piping to a point above the horizontal or branch connection to the riser as at b, detail D, the riser will be completely sealed from the main and its steam supply closed. This is a practical objection to the one-type relief system and should always be borne in mind when designing this type of system.

Work Problem S-7-7

Details E, F and G, illustrate approved methods for making what is commonly referred to as a "swing" or "swivel" connection. It is essential that all branch connections should be made so as to allow a "swing" at the main and at the other end. When using a "swing" or "swivel" connection, it is necessary to anchor the pipe at two or more points. The expansion is taken up by a slight turning at the screwed joints. The arrangements, however, shown as details E, F and G, offer increased resistance due to the extra fittings used and should have proper consideration.

Work Problem S-7-8

Detail H, Fig. S-7-4, may be used with care where a main makes a turn of 90 degrees. Under such circumstances, expansion is partly absorbed by the spring of the members.

Work Problem S-7-9

Details I and J, Fig. S-7-4, illustrate a proper and improper method of reducing the size of the main on the run. The use of a straight reducer as per detail I permits water to accumulate in shallow pockets, reducing the pipe area, and resulting in water-hammer when starting up the circulation. Detail J shows the proper method whereby the use of an eccentric reducer will avoid this impractical condition.

Work Problem S-7-10

EXPANSION IN RISERS

Expansion in risers in small buildings where the supply mains are in the basement is usually downward and the movement is provided for by the slight spring of the branches and by the turning of screwed fittings connecting the branches to the main as already explained.

In larger buildings with a main in the attic, the risers are anchored near the middle of their length and expansion is permitted to take place in both directions. When the usual branch connection at the top and at the bottom of the riser cannot handle properly the total expansion, a flexible connection for the riser as shown in detail K, Fig. S-7-4, must be used. This provides a swivel joint and is especially suitable when the basement main must be installed near the foot of the riser. Although the additional resistance, due to extra fittings, is a disadvantage, it is outweighed by the flexibility provided. This arrangement may generally be expected to care for expansion in risers for buildings as high as eight stories.

Work Problem S-7-11

The illustration shown as detail K, Fig. S-7-4, is known as an expansion loop and is used for risers in buildings having more than eight stories. It can be expected to care for expansion and provide suitable flexibility for four stories on each side of the anchor.

Work Problem S-7-12

DRIP CONNECTIONS AND VENTS

Detail M, Fig. S-7-4 shows an accepted satisfactory method for dripping a main where it rises to a higher level, while detail N, same figure, illustrates a drip and vent connection for the end of the main. Air accumulates in the system, especially when it is not under steam, and when started up, the air is forced to the end of the main or other air-pocket locations. All piping designs should be finally studied and all air pockets located. At each such point air valves should be specified.

Where there may be more than one main, two or more drips from different mains should not be connected to one another above the water line since the pressure of the steam in them may not be the same. The result will be interference in the flow of condensation with consequent water-hammer.

Work Problem S-7-13

It is necessary frequently to loop a steam main around a beam. Detail O, Fig. S-7-4, illustrates the proper arrangement of fittings to overcome this obstacle. Detail P, same figure, shows how a dry return main may be looped around a door or other opening.

Work Problem S-7-14

RADIATOR CONNECTIONS

Connections to radiators should always be made so that the main or riser or both may expand freely without straining the fittings at any point and at the same time drain the radiator properly and be free from water pockets. Many and varied conditions arise under which radiators must be installed. It is obviously possible to illustrate only those which may be classed as the more or less typical.

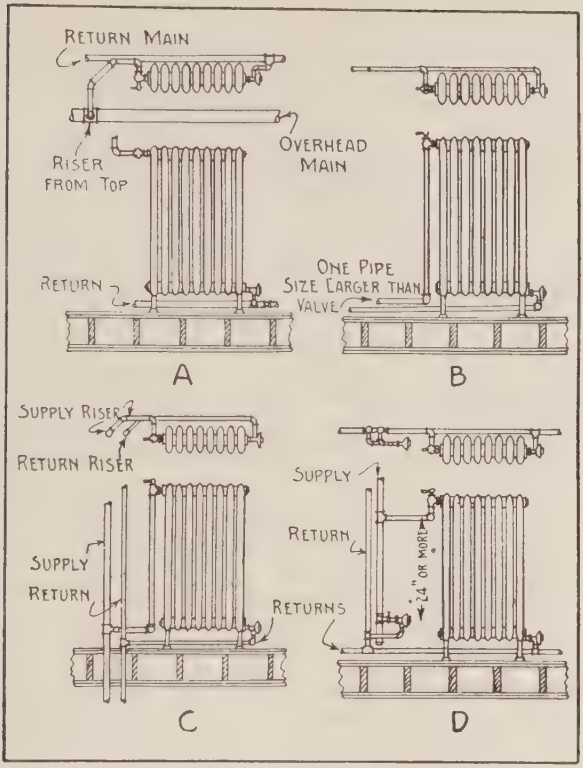


Fig. S-7-5. Radiator Connections

Fig. S-7-5 shows four conditions of installation. In detail A, the radiator is supplied from an overhead main while return main is at the floor. Detail B shows a radiator with supply and return at the floor connected to risers located some distance from the radiator. Detail C shows similar connections to the risers near the radiator while detail D illustrates required piping arrangement where a radiator is supplied from a drop riser and with return at the floor line.

It should be observed that in each detail there are no "stiff" connections. The riser is free to move vertically and grade of pipes is ample, assuring positive drainage.

Work Problem S-7-15

PART S.

STEAM HEATING SYSTEMS

LESSON 8.

Designs and Reports

STEAM HEATING SYSTEMS.

In the preceding seven lessons, different types of steam systems have been illustrated and data and tables presented for assistance in designing and installing this character of heating work. The student should realize, however, that no piping schedule can be expected to apply under all conditions. To him who is beginning the study of heating and ventilating engineering and to those who may think that heating is an exact science, capable of being reduced to standard tables and "thumb" rules, let a final note of warning be sounded lest he fall into the pit of sad mistakes.

Seldom is it possible to design and install exactly similar systems. Experienced heating and ventilating engineers realize only too well that every successful and satisfactory plant should have special consideration in its design, that it may properly meet the conditions existing in the particular building to be heated and fulfill the duties for which it is intended.

While many tables have been presented in lessons preceding, they should not be accepted and applied as hard-and-fast rules, but should be taken rather as guides. The size of riser is not alone determined by the size of the radiator it serves; it depends more upon the number of connections and the length of lateral branches.

It is advisable in most cases to design a lateral branch and riser at least one pipe size larger than the radiator valve and when branches and risers are exceptionally long or contain a considerable number of turns, two pipe sizes larger than the radiator valve may be the proper allowance to assure unquestioned service. And when so designed, the reduction in size should be made just at the valve using a reducer or a reducing elbow and nipple.

When cutting, threading and installing pipe, special care should be exercised to see that the work is done in a high-class manner and that nothing is left undone that will assist toward reducing friction of flow to a minimum. The ends of all pipe should be reamed. To fail to observe this requirement is an indication of "sloppy" work. Unreamed pipe can reduce the internal area and introduce enough friction to affect very materially the flow of the heating medium therein. The fitter in charge of installation work should see, so far as is possible, that every piece of pipe is "looked through" before it is placed permanently. Difficulties due to complete stoppage of flow within the pipe itself thus may often be avoided.

PLANS DESIRABLE

It is in the interest of economy and satisfactorily completed jobs that a piping plan should always be made. Plans thus made should show construction of details clearly. Practically every piece of pipe, for supply and return lines should be clearly shown and each fitting appropriately marked where there is any doubt concerning the ability of the estimator or installer to interpret it correctly. Steamfitters seldom go wrong when they are provided with well-prepared construction details.

In preparing a piping design, it is best to follow and follow a plan of action. It is impossible to lay some definite plan of procedure. Undoubtedly, each student who may complete this course of study, conscientiously or unconscientiously, will formulate the student to decide how best to solve his par- down fixed and unalterable rules for such work— the way only can be indicated—it must be left to ticular problems. The following is therefore of- fered as a guide only:

TO PROPORTION THE MAIN

First: Make a preliminary list of the sizes of the pipe required by beginning at the section of the main which supplies the last group of radiators. In making this list, the size of pipe required to sup- ply the stated radiating surface may be taken from the proper table, disregarding at this time the length of the run. A list of the sizes of the main all the way back to the boiler to accommodate the various radiator groups should thus be prepared.

Second: The list as prepared under *First* should be considered as preliminary only. Using the size as noted and starting at the boiler, the equivalent length of run to each take-off for a riser should be estimated. This equivalent length of main to any riser will be equal to the actual length as scaled from the plans, increased by amounts to com- pensate for all the various fittings which occur in the run between the boiler and the branch take-off.

In other words, conditions assumed are as if the size of pipe required to supply the radiation at any point (and this includes the radiation supplied to the riser in question and all radiation required be- tween the take-off and the end of main) were to run for the entire distance back to the boiler and were to carry the quantity of steam required for this radiation. To this length is added the equiv- alent length for each fitting, such equivalent length being based on the size of pipe where the fitting will be located.

Third: Commence again at the last group of ra- diators on the run. The equivalent length from the boiler to the take-off for this group is now known. If this length is not greater than the maxi- mum given in the table, then no section of the main

will be required to supply radiation for a length greater than the maximum, and the preliminary sizes of pipe as found under *First*, above, may be used throughout.

Fourth: If, however, the length found is greater than the maximum given in the table, then a proper correction of allowance for increased length must be applied. This should be done for each group of radiators served until a point along the main where the length is less than the maximum allowed is reached. From this point to the boiler, the preliminary sizes as found under *First* may be adopted.

Considering for the moment a system in which a considerable amount of radiation must be supplied through a long run of pipe, with a definite initial pressure of say 5.3 lbs. at the boiler, there will be a loss in pressure between the boiler and the end of the run. This pressure loss will increase as the quantity of radiation supplied increases and as the run becomes longer. Procedure should be as follows:

First: Select a point on the run which point is at the take-off approximately two-thirds the actual length from the boiler to the end of the main. Assume, for the moment, a pressure drop of 2 lbs. between the boiler and the point in question.

Second: Consider this location as a point of new initial pressure for all piping between this point and the end of the main. This new initial pressure will be equal to the original pressure less 2 lbs. or it may be assumed at 3.3 lbs.

Third: Sizes of all pipes from this point of new initial pressure to the end of the main may be taken from a table giving values for 2 lbs. pressure and sizes from this point back to the boiler may be taken from a table giving values for 5 lbs. pressure.

Note: While 5 lbs. and 2 lbs. initial steam pressure have been used in the above explanation, the method as outlined may be applied in principle for any pressures.

The following modification of the above method for establishing the size of a steam main when taking the length into consideration should be observed.

A. Make two preliminary pipe size lists—one from the end of the main to the point of assumed new initial pressure (using the proper data) and the other from this point to the boiler (using a proper table).

B. Determine equivalent lengths for each section of run—boiler to point of new initial pressure and from there to end of main—in reality, two separate mains with different initial pressures are assumed and then procedure is as outlined above.

BASEMENT HEATING PLAN

Fig. S-8-1 shows a basement heating plan for a one-pipe circuit steam system which is to be completed by the student. The steam main leaves the boiler at A and continues to B where it branches. The branch B, C, D, E, F supplies the greater amount of radiation. The other branch leaving the main at right angles to the main flow line supplies radiators on line B, G, H, I.

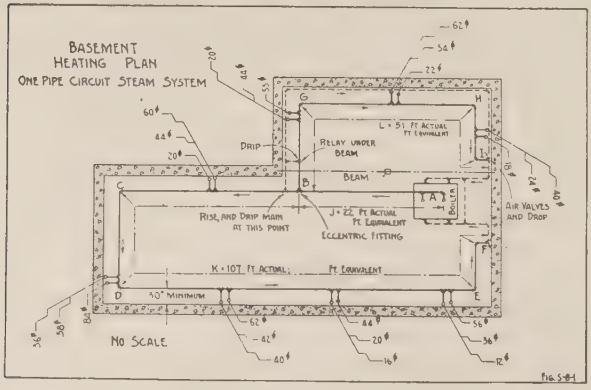


Fig. S-8-1. Basement Heating Plan, One-Pipe Circuit Steam System.

It should be noted that an eccentric fitting should be used at point B, and that relays are required on the B-G and B-C lines in order to pass under the beam and to provide proper pitch for the long run. The student is to determine the size of all piping and note same so that a steam fitter would have all necessary information to install the work. The

student will also prepare an enlarged sketch showing clearly the piping detail at point B, the relay under the beam and the relay on line B-C. Note: The work for the following assigned problem should be carefully prepared and preserved, in order that it will be in suitable shape when needed in the estimating part of the course.

Work Problem S-8-1

SIMPLE STEAM HEATING SYSTEM FOR ONE-STORY BUILDING, WITHOUT BASEMENT

Fig. S-8-2 shows a plan view with part section of a one-story building without cellar. The boiler is located in a small excavated part in one corner. An overhead steam main is indicated. All radiators are shown in plan. Two are shown in elevation. The system of piping is to be shown on the plan while in the sectional view the student will indicate

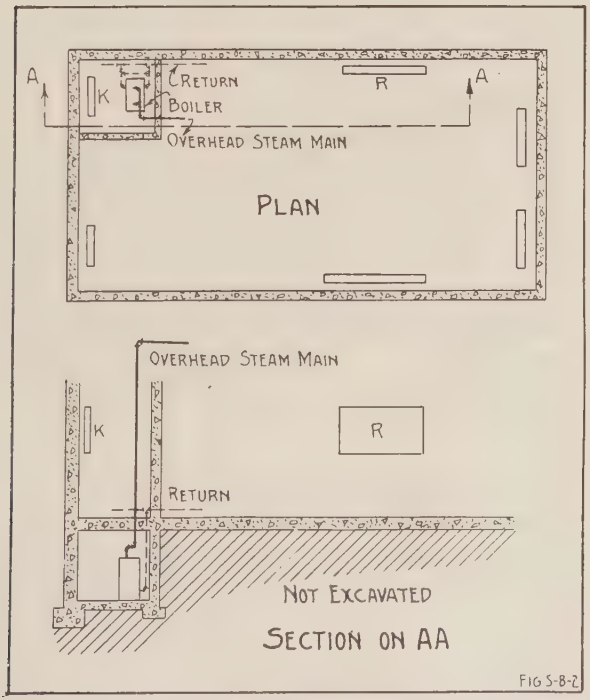


Fig. S-8-2. Small Building Without Basement to be Piped for an Overhead, Downflow One-Pipe Circuit Steam Heating System

the necessary method of piping between radiator R and the boiler in order that all drips from drop risers and the returns from all radiators may be connected directly into the main return without the possibility of short circuiting the steam flow through radiators near the boiler. No traps are to be used on the radiators. No sizes of pipe are required.

Work Problem S-8-2

ONE-PIPE STEAM SYSTEM THAT FUNCTIONS POORLY

The one-pipe steam heating system shown in Fig. S-8-3 functions poorly. The student should study this design and prepare a report thereon as required in the following assigned problem. The system of piping is shown on the first-floor plan. Radiators on this floor are therefore shown in true position with risers to second floor indicated.

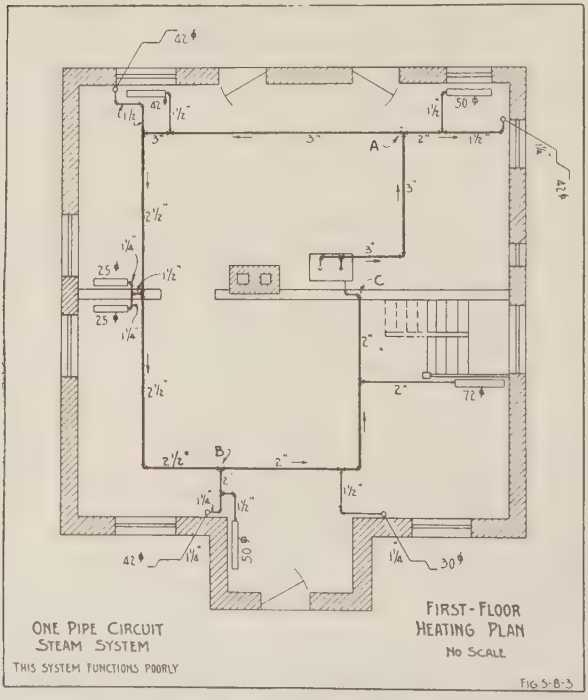


Fig. S-8-3. A Poorly-Functioning One-Pipe Steam System

A 3-in. steam main is supplied from two steam outlets on the boiler. The steam main grades up to point A, a distance of about 15 ft. from the boiler. This grading up to point A is done on account of insufficient head room to maintain proper grade throughout entire run. At this point a $3 \times 2 \times 3$ tee is used to supply radiators in two directions. The manner in which this tee is placed in the line is usually referred to as "bull-head" style. The 2-in. branch supplies two radiators, a first-floor radiator of 50 sq. ft. and a second-floor radiator of 42 sq. ft.

From point A, the 3-in. branch is graded downward with a pitch of about 1 in. per 10 ft. to a $2\frac{1}{2}$ in. $\times$ $1\frac{1}{2}$ in. $\times$ 3-in. tee placed in the line in the same manner as the tee at point A. The main is carried $2\frac{1}{2}$ in. as far as point B where it is reduced to a 2-in. line. This size is carried to point C, rather near the boiler, where it drops and is connected into the return.

The system as shown and described does not function properly. The end of the main at C is too near the boiler water-line. The main frequently floods.

Two reports are required. (a) The student is to assume that the drop in pressure at the end of the main, point C, is not too great and to suggest most simple means for improving conditions. (b) The student is to consider that the system is to be remodeled so that the drop in pressure from the boiler to the end of the main will be considerably less than the present design allows.

Work Problem S-8-3

POOR STEAM DESIGN

Fig. S-8-4 shows a run of steam piping supplying two small radiators which are located fairly close to the boiler. When the system is in operation, water from the automatic air valve is thrown to the ceiling.

The student will explain (a) why water is thrown off in this manner and how to correct the trouble, (b) whether the layout could be improved

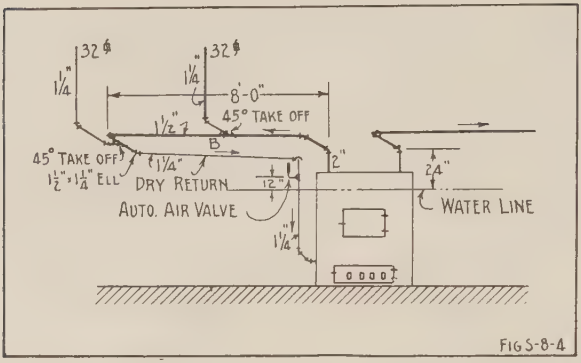


Fig. S-8-4. Piping of Two Steam Radiators Near the Boiler for Criticism and Report by the Student

by the use of fewer fittings, and if the design represents poor practice in the use of size of pipe or fittings, what should be done to improve without considerable change, (c) submit a pencil sketch showing a better and cheaper way to supply these two radiators.

Work Problem S-8-4

CHANGING ONE-PIPE STEAM HEATING SYSTEM TO A VAPOR PLANT

Many one-pipe steam heating systems have been remodeled into vapor systems through changing the radiator valves, installing radiator traps on the return side of the radiators and running the necessary return piping to an air eliminator or return trap.

Fig. S-8-5 shows a one-pipe steam heating system which is to be so remodeled using a return trap in a position approximately as shown. The student will indicate on this figure all necessary equipment, change of piping, and new piping. He will prepare this figure so that an estimate of material could be made therefrom by noting clearly all requirements.

Work Problem S-8-5

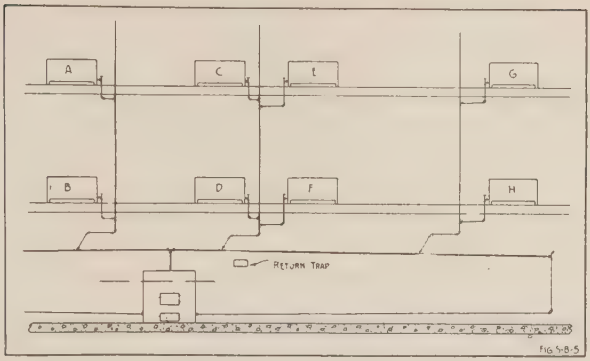


Fig. S-8-5. A One-Pipe Steam System to be Converted into a Vapor System Without Removing Present Piping

PREPARATION OF DESIGNS.

The preparation of a design and estimate for a steam heating system represents several distinct operations. Comparable bids from several firms cannot be obtained unless the basis for the bids is the same, nor can a correct estimate be submitted for a system of steam heating without first having properly designed the system and prepared a plan from which all quantities of material may be taken and a reasonably safe estimate of labor made therefrom.

Then, again, each job that passes through an office should be done in such a way as to contribute something toward making subsequent estimates more positive as to correctness. Consequently, the more carefully prepared and systematically executed, just so much more will every design give more reliable information. Every business man must develop for himself methods by which he may be a more successful merchant. Various forms for carrying forward a heating design may be developed to suit needs; so, in presenting those that follow, no claim is made that they are ideal or that they necessarily should be adopted by every individual. They are used primarily to teach the student system in handling such work. By employing some similar systematic plan for recording design calculations and estimating costs (to be discussed in

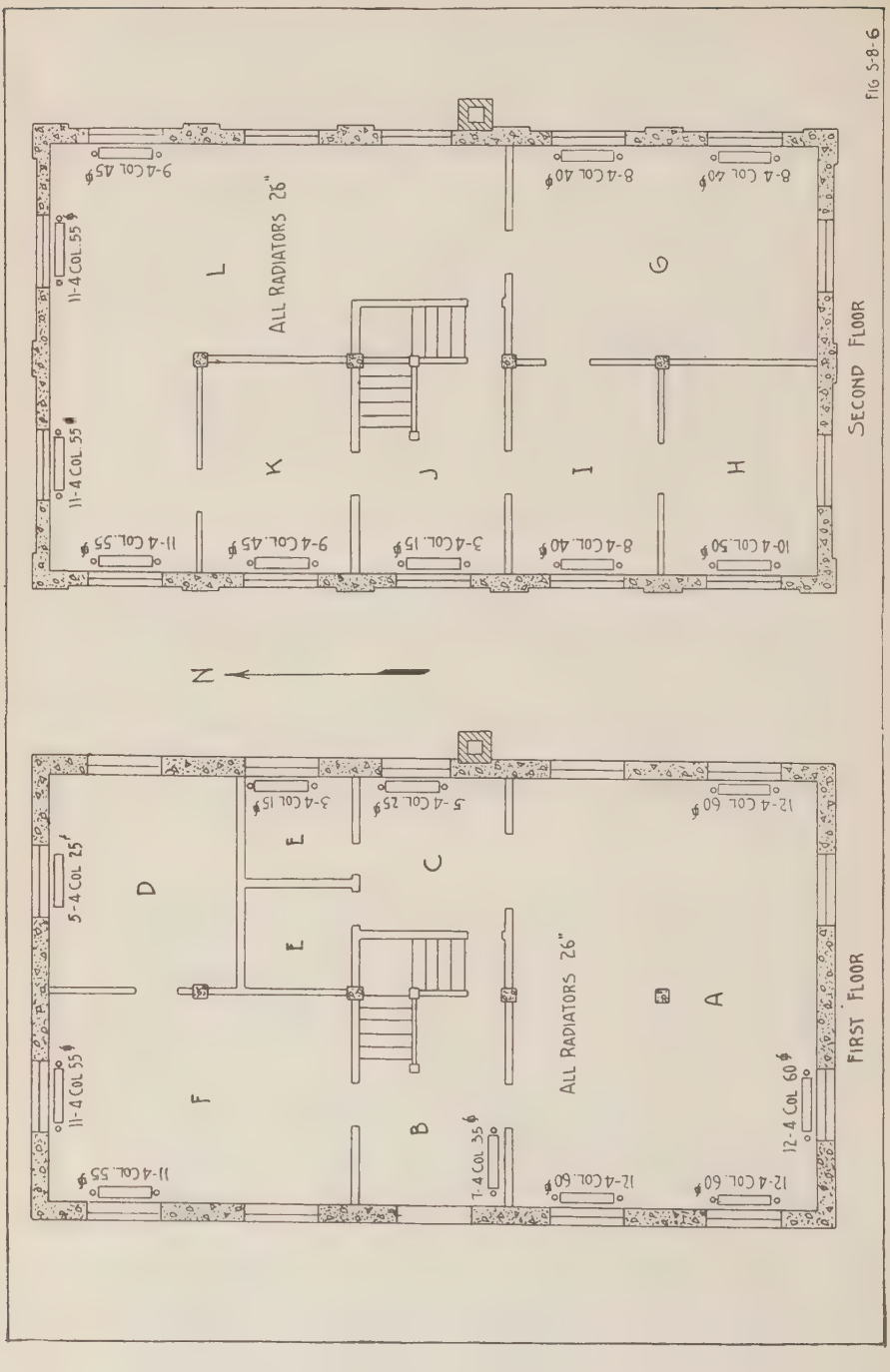


Fig. S-8-6. Floor Plans for an Office Building for Which a Vapor Heating System is to be Designed

TABLE S-8-1. FIELD DATA FOR FIGURING HEATING SYSTEM FOR OFFICE BUILDING

FIELD DATA FOR HEAT LOSS CALCULATIONS

Floor.	Room Designation	Wall	Gross Exposed Wall Dimensions and Areas Sq. Ft.	Glass and Door Surface in Exposed Walls: Dimensions and Areas, Sq. Ft. — Glass	Door	Total Glass	Door	Net Exposed Wall Areas Sq. Ft.	Infiltration: Wall	Linear Feet of Crack around Windows and Doors in Walls for which Leakage is Considered	Volume: Dimensions and Cubical Contents Cu. Ft.	Areas: Floor Dimensions Areas Sq. Ft. (If Heat Loss Occurs)	Areas: Ceiling Dimensions Areas Sq. Ft. (If Heat Loss Occurs)
1st	A	W	27'×9' = 243	2(6×6) = 72	—	72	171	W	2(4×6) = 48	27'×39'×9' = 9450	27'×39' = 1050	—	
		E	27'×9' = 243	2(6×6) = 72	—	72	171	—	—				
		S	39'×9' = 351	2(6×6) = 72	—	72	279						
1st	B	W	13'×9' = 117	—	6×7½=45	45	72	W	2×6 = 12 2×7½ = 15 27	13'×22'×9' = 2580	13'×22' = 286	13'×22' = 286	
		—	—	—	—	—	—	—	—				
		—	—	—	—	—	—						
1st	C	E	13'×9' = 117	6×6 = 36	—	36	81	—	—	13'×13'×9' = 1520	13'×13' = 169	—	
		—	—	—	—	—	—	—	—				
		—	—	—	—	—	—						
1st	D	N	20'×9' = 180	6×6 = 36	—	36	144	N	4×6 = 24	20'×17½'×9' = 3150	—	20'×17½' = 350	
		E	17½'×9' = 158	6×6 = 36	—	36	122	—	—				
		S	18'×9' = 162	—	—	—	162						
1st	E	E	9½'×9' = 86	6×6 = 36	—	36	50	—	—	9½'×18'×9' = 1540	9½'×18' = 171	—	
		—	—	—	—	—	—	—	—				
		—	—	—	—	—	—						
1st	F	N	19½'×9' = 176	6×6 = 36	—	36	140	N	4×6 = 24	19½'×27'×9' = 4730	19½'×27' = 526	—	
		W	27'×9' = 243	2(6×6) = 72	—	72	171	W	2(4×6) = 48				
		E	16'×9' = 144	—	—		144						
2nd	G	E	27'×9' = 243	2(6×6) = 72	—	72	171	—	—	27'×19'×9' = 4610	27'×19' = 512	27'×19' = 512	
		S	19'×9' = 171	6×6 = 36	—	36	135	—	—				
		—	—	—	—	—	—						
2nd	H	W	13'×9' = 117	6×6 = 36	—	36	81	W	4×6 = 24	13'×19'×9' = 2230	13'×19' = 247	13'×19' = 247	
		S	19'×9' = 171	6×6 = 36	—	36	135	—	—				
		—	—	—	—	—	—						
2nd	I	W	12'-9"×9' = 115	6×6 = 36	—	36	79	W	4×6 = 24	12'-9"×17'-6"×9' = 2010	12'-9"×17'-6" = 223	12'-9"×17'-6" = 223	
		N	17'-6"×9' = 158	—	—	—	158	—	—				
		—	—	—	—	—	—						
2nd	J	W	13'×9' = 117	6×6 = 36	—	36	81	W	4×6 = 24	13'×17'-6"×9' = 2050	13'×17'-6" = 227	13'×17'-6" = 227	
		S	17½'×9' = 158	—	—		158	—	—				
		N	17½'×9' = 158	—	—	—	158						
2nd	K	W	13'×9' = 117	6×6 = 36	—	36	81	W	4×6 = 24	13'×17'-6"×9' = 2050	—	13'×17'-6" = 227	
		S	17½'×9 = 158	—	—	—	158	—	—				
		—	—	—	—	—	—						
2nd	L	N	38'×9' = 342	2(6×6) = 72	—	72	270	N	2(4×6) = 48	13'-6"×38'×9' = 4620 26'×18'×9' = 4200 8820	13'-6"×38' = 512 26'×18' = 468 980	13'-6"×38' = 512 26'×18' = 468 980	
		W	13½'×9' = 122	6×6 = 36	—	36	86	W	4×6 = 24				
		E	39'×9' = 351	3(6×6) = 108	—	108	243						

SLIDE RULE COMPUTATIONS

following lessons) permanent and oftentimes invaluable records are available.

The work may be grouped under three heads:

(a) Field data as basis for design.

(b) Office calculations for heating requirements.

(c) Preparation of plans for estimate and installation.

A complete design for a vapor heating system for a two-story office building will be carried through in detail. Fig. S-8-6 shows the two floor plans. The student should assume temporarily that the radiators (shown thereon) have not been determined as to size or location.

The first step is to "measure-up" the plans or the building if it is already built, and plans are not available. Table S-8-1 contains spaces for recording all necessary dimensions and for calculating the areas of all surfaces for which heat transmission must be figured. The data contained in this table do not depend upon the type of system to be installed. The correctness of these data is essential else any error therein contained will be carried through all calculations embodying these fundamental design figures. Field data recorded in the manner presented afford easy means for checking. These data when so presented may be collected and compiled by one person and used by another with perfect assurance of understanding.

The second step is to transfer from Table S-8-1 the net areas required. Thus, net areas for wall, glass and door respectively are noted in columns 4, 7, and 10 of Table S-8-2 and linear feet of crack opening around windows or doors used as the basis for infiltration losses listed in Column 16. Net areas for ceilings or floors through which heat may be lost or gained are noted in Columns 19 and 22 respectively. Room designations having been properly filled in, there is included within the same space, the temperature at which this particular room is to be maintained.

Further progress is impossible without detailed data on construction details and operating conditions. It should therefore be obtained and noted in easy reference form, somewhat as follows:

DATA

Walls: Outside, 4-in. brick, 12-in. hollow tile plastered.

Partition, 4-in. hollow tile, plastered both sides.

Windows: Single thick glass, in wood frames.

Door: 1¾ in. T. and G.

Temperature: Outside, 0° F.

Inside (as given in Column 2, Table S-8-2)

Basement, 50° F.

Attic, 40° F.

Exposure Allowances:

North, 25%

West, 20%

East, 10%

South, 0%

Infiltration Data (figured for north and west sides):

Double hung window.

Interlocking-type weather strip.

Wind velocity, 20 miles per hour.

Plain door.

The next step is to refer to proper heat loss coefficient tables (as are given in Lesson 2 of Part 1) and note the value of coefficient "f" for wall, glass, door, ceiling, and floor. Space is provided in Table S-8-2.

Thus, the following values are obtained: For wall, f = 0.18; for glass, f = 1.10; for door, f = 0.42; for inside wall, f = 0.50; for ceiling and floor, f = 0.36. As these values are for B.T.U. per hour per 1° F., the value to use as a multiplier of net area is obtained from the product of the value of "f" times difference in temperature between the inside and outside. Hence the coefficient for Column 5 for room A is 80 × 0.18 = 14.4. Other values in this column as well as those in columns 8, 11, 20 and 23 are obtained in a similar manner.

Work Problem S-8-6

Having these values correctly prepared, the product of the area (Col. 4) × the coefficient (Col. 5) for each wall of each room will show the B.T.U. loss through them as recorded in Column 6. Thus for the west wall of room A, 171 × 14.4 = 2460 B.T.U.

In a similar manner values in Columns 9, 12, 21, and 24 are obtained.

The next step is to obtain total B.T.U. loss for each wall of each room as given in Column 13 by adding the values in Columns 6, 9, and 12. These additions should be made for the respective walls and not for the entire room in order that different exposure factors may be correctly applied. Thus for west wall of room A:

$$2460 + 6320 + 0 = 8780 \text{ B.T.U.}$$

Exposure factors are next noted in Column 14 and then applied and the results recorded in Column 15. Thus, for west wall of room A:

$$8780 \times 1.25 = 10750 \text{ B.T.U.}$$

The value for the infiltration coefficient should next be established. Reference to Table 19, Part 1 shows a value of 1.98 B.T.U. per foot of crack per mile of wind velocity per 70° F. This will be $1.98 \div 70 = 0.028$ for 1° F. and the value for Column 17 for windows becomes 0.028×80 (deg.) $\times 20$ (m.p.h.) $= 45$ B.T.U. per linear foot of crack opening.

The value for a plain door is 8.36 B.T.U. per mile of velocity per 70° or $8.36 \div 70 = 0.12$ per 1°.

Work Problem S-8-7

The next step is to total all B.T.U. losses and record same in Column 25. The losses from the respective walls need no longer be carried independently. Thus, for room A, the total hourly B.T.U. loss becomes $10750 + 9640 + 10320 + 2160 + 11350 = 44220$ B.T.U. It should be noted in the case of some of the rooms that there is a negative loss. If this is not clear to the student, he should review Lesson 2 of Part 1.

Work Problem S-8-8

The heat loss computations are now completed and systematically recorded on one sheet. They may readily be checked. The values in the last column form the basis for establishing the radiating areas.

Since there will be several different temperature ranges, if the student is not familiar with the determination of the proper radiator coefficient he should review Lesson 2 of Part 1 where the subject is covered in detail.

The following data are needed:

Heating medium, vapor.

Temperature of steam vapor (assumed at atmospheric temperature) = 212° F.

Radiator coefficient (Table R-2-1) = 1.55.

Still air at 70° F.

Radiators,—26-in. 4-col. (5 sq. ft. per section).

Radiation emission for the different rooms is tabulated by steps in Table S-8-3, Columns 1 to 7 inclusive. The values in Column 8 are obtained from Table S-8-2, Column 25. Simple division of the value in Column 8 by value in Column 7 shows the square feet of radiating surface required for each of the rooms. Reference to Table R-1-1 permits selection of proper size radiators as noted in Columns 10, 11, and 12. The last column contains the radiator stub spacing.

Work Problem S-8-9

The radiators should next be located on the floor plans as shown in Fig. S-8-6. They should preferably be drawn to scale and described with appropriate simple notes as indicated.

With the foregoing material at hand, the basement plan (see Fig. S-8-7) may now be prepared. The boiler should be blocked in at the proper location and risers shown in correct positions by small circles. The piping run should then be studied and the best and most economical design established. No sizing of pipes should be made until the arrangement has been definitely decided.

Risers should then be laid down as indicated in Fig. S-8-7. Thus, all piping can be shown on this one plan. The areas of radiators supplied should be noted near the riser terminus.

Pipe sizes should be established for all parts of and after having assured himself that he is familiar towards the boiler.

The student should study this layout carefully, the risers first, before sizes for any of the branches or parts of the main are established. For a vapor system of this kind, the sizing of the main may begin at the last radiator served and progress with the design and details therefor, work the following problem.

Work Problem S-8-10

TABLE S-8-2. HEAT LOSS CALCULATIONS FOR OFFICE BUILDING

HEAT LOSS CALCULATIONS — B.T.U. METHOD

Floor	Room Designation	Wall	Wall: Transmission Factor Per 1°F = 0.18 / 0.50; Net Sq. Ft.	Wall: Coef.	Wall: B.T.U.	Glass: Transmission Factor Per 1°F = 1.10; Net Sq. Ft.	Glass: Coef.	Glass: B.T.U.	Door: Transmission Factor Per 1°F = 0.42; Net Sq. Ft.	Door: Coef.	Door: B.T.U.	B.T.U. Loss Wall Glass Door Col. 6+9+12	Exposure Factor	B.T.U. Loss Wall Glass Door Include Exposure	Infiltration 0.028; 0.12 B.T.U. per Ft. Crack p. 1° p. Hour p. Mile Vel.; Lin. Ft.	Infiltration: Coef.	Infiltration: B.T.U.	Ceiling: Transmission Factor Per 1°F = 0.36; Net Sq. Ft.	Ceiling: Coef.	Ceiling: B.T.U.	Floor: Transmission Factor Per 1°F = 0.36; Net Sq. Ft.	Floor: Coef.	Floor: B.T.U.	Total B.T.U. Loss Cols. 15 + 18 + 21 + 24
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1ST	A 80°	W	171	14.4	2460	72	88	6320	—	—	—	8780	1.25	10750	48	45	2160							
		E	171	14.4	2460	72	88	6320	—	—	—	8780	1.10	9640	—	—	—	—	—	—	1050	10.8	11350	44220
		S	279	14.4	4000	72	88	6320	—	—	—	10320	1.00	10320	—	—	—							
1ST	B 70°	W	72	12.6	868	—	—	—	45	29.4	1320	2188	1.20	2625	27	39	1060							
		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	286	3.6	1030	286	7.2	2050	6765
		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—							
1ST	C 70°	E	81	12.6	977	36	77	2770	—	—	—	3747	1.10	4119	—	—	—							
		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	169	7.2	1220	5339
		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—							
1ST	D 50°	N	144	9.0	1296	36	55	1980	—	—	—	3276	1.25	4095	24	29	698							
		E	122	9.0	1098	36	55	1980	—	—	—	3078	1.10	3386	—	—	—	350	3.6	-1260	—	—	—	5299
		S	162	10.	-1620	—	—	—	—	—	—	-1620	1.00	-1620	—	—	—							
1ST	E 70°	E	50	12.6	603	36	77	2770	—	—	—	3373	1.10	3710	—	—	—							
		N	162	10.	-1620	—	—	—	—	—	—	-1620	1.00	-1620	—	—	—	—	—	—	171	7.2	1230	3320
		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—							
1ST	F 70°	N	140	12.6	1688	36	77	2770	—	—	—	4458	1.25	5573	24	39	930							
		W	171	12.6	2062	72	77	5544	—	—	—	7606	1.20	9125	48	39	1860	—	—	—	526	7.2	3780	22708
		E	144	10.	1440	—	—	—	—	—	—	1440	1.00	1440	—	—	—							
2ND	G 70°	E	171	12.6	2060	72	77	5540	—	—	—	7600	1.10	8360	—	—	—							
		S	135	12.6	1628	36	77	2770	—	—	—	4398	1.00	4398	—	—	—	512	10.8	5530	512	3.6	-1840	16448
		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—							
2ND	H 70°	W	81	12.6	977	36	77	2770	—	—	—	3747	1.20	4496	24	39	930							
		S	135	12.6	1628	36	77	2770	—	—	—	4398	1.00	4398	—	—	—	247	10.8	2660	247	3.6	-885	10669
		—	—	—	—	—	—		—		—	—	—	—	—	—	—							
2ND	I 70°	W	79	12.6	953	36	77	2770	—	—	—	3723	1.20	4467	24	39	930							
		N	158	10.	1580	—	—	—	—	—	—	1580	1.00	1580	—	—	—	223	10.8	2410	223	3.6	-802	8585
		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—							
2ND	J 60°	W	81	10.8	875	36	66	2370	—	—	—	3245	1.20	3894	24	35	840							
		N	158	10	-1580	—	—	—	—	—	—	-1580	1.00	-1580	—	—	—	227	7.2	1620	227	3.6	-815	2379
		S	158	10.	-1580	—	—	—	—	—	—	-1580	1.00	-1580	—	—	—							
2ND	K 70°	W	81	12.6	977	36	77	2770	—	—	—	3747	1.20	4496	24	39	930							
		S	158	10.	1580	—	—	—	—	—	—	1580	1.00	1580	—	—	—	227	10.8	2450	—	—	—	9456
		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—							
2ND	L 70°	N	270	12.6	3256	72	77	5540	—	—	—	8796	1.25	10996	48	39	1860							
		W	86	12.6	1037	36	77	2770	—	—	—	3807	1.20	4568	24	39	930	980	10.8	10600	350	7.2	2520	43824
		E	243	12.6	2930	108	77	8300	—	—	—	11230	1.10	12350	—	—	—							

SLIDE RULE CALCULATIONS

TABLE S-8-3.—RADIATION REQUIREMENTS

Room	Room Air Temp., deg. F.	Temp. Heating Medium, deg. F.	Temp. Range, deg. F.	Diff. above or below Standard (150°) deg. F.	Radiator Co-efficient	Radiation Emission B.T.U. per hour per sq. ft.	B.T.U. Loss per Hour	Area Radiation Surface Required, Sq. ft.	Radiators Selected			Radiator Stub Spacing, In.
									No. Rad.	No. Sec.	Actual Surface, Sq. ft.	
1	2	3	4	5	6	7	8	9	10	11	12	13
A	80	212	132	−18	1.55	198	44220	222	4	12	240	37
B	70	212	142	−8	1.55	216	6765	31	1	7	35	22
C	70	212	142	−8	1.55	216	5339	25	1	5	25	16
D	50	212	162	+12	1.55	257	5299	21	1	5	25	16
E	70	212	142	−8	1.55	216	3320	15	1	3	15	10
F	70	212	142	−8	1.55	216	22708	105	2	11	110	34
G	70	212	142	−8	1.55	216	16448	76	2	8	80	25
H	70	212	142	−8	1.55	216	10669	50	1	10	50	31
I	70	212	142	−8	1.55	216	8585	40	1	8	40	25
J	60	212	152	+2	1.55	237	2379	10	1	3	15	10
K	70	212	142	−8	1.55	216	9456	44	1	9	45	28
									3	11	165	34
L	70	212	142	−8	1.55	216	43824	200	1	9	45	28
Total							179012		20		890	

Each of the three parts of a steam boiler has a distinct function to perform, and in a properly-designed and operated boiler, the functions of the different parts are harmonized and co-ordinated.

The furnace or firebox should be so designed as to promote as nearly perfect combustion of the fuel as possible, in order that all the heat contained in the fuel may be liberated.

The boiler proper should have ample capacity to hold the required quantity of water and should have the heating surfaces which absorb the heat from the fire and conduct it to the water so distributed with reference thereto, and so designed with regard to areas in contact with the fire and gases of combustion, as to assure a maximum extraction of heat therefrom before the gases pass into the smoke flue.

The steam space should be amply large and its horizontal area, with reference to the water surface area, should be such as to assure prompt separation of the steam from the water, in order that the steam may be delivered into the distributing system as dry as possible.

Work Problem B-1-1

PRINCIPLES OF OPERATION

When heat developed in the furnace is applied to the boiler, immediately there is a movement of water established. The layers of water in contact with the heating surfaces, becoming higher in temperature, expand, become lighter in weight per unit volume, and hence, rise to make room for the colder and heavier water. This rise in temperature continues, increasing in rapidity as more heat is added to the water.

When all of the water in the boiler is heated to a temperature approximately equivalent to the respective boiling point, small globules of steam form on or adjacent to the inner surface of the boiler in contact with the fire. These small particles of steam, being many times lighter in weight than the water, seek to rise rapidly to the water surface. If they are hindered in their upward movement, or if this tendency to free themselves from

the water is interfered with, the combined volume of water and globules increases rapidly, with the result that the surface of the water in the boiler rises and what is known as priming occurs. Therefore, it is essential that all water passages in the boiler be amply large to permit or, better still, to assure free upward movement and positive and quick release of these steam globules from the water at its surface.

Work Problem B-1-2, B-1-3

With such release of steam from the water surface, the steam space above the water soon fills and, as boiling continues and more steam is delivered into this space, the steam becomes denser, with the result that a pressure is gradually built up in the boiler. Steam, then, may be delivered into the distributing system, and, if the boiler is capable of evaporating water at a rate equal to or greater than the rate at which the radiation on the system condenses the steam therein, then continuous operation may be maintained by burning fuel at such a rate as will supply the required amount of heat.

Work Problem B-1-4

CLASSIFICATION

Heating boilers properly are classified under two main heads according to the material of which they are built, namely, (1) cast iron, and (2) steel.

Work Problem B-1-5

The cast-iron boiler is found in three distinct types: (a) round boiler, (b) sectional boiler, (c) smokeless or down-draft boiler. The steel boiler appears in two distinct types, (a) the portable, (b) the brickset, both of which are built for direct-draft or down-draft (smokeless) operation. The portable steel boiler is built as a vertical and as a horizontal boiler, the horizontal appearing as the return-tubular type, the firebox type, and the internally-fired or marine type. The brickset boiler is built as the firebox type and the horizontal return-tubular type.

Work Problem B-1-6

CAST-IRON BOILERS

In Fig. B-1-1 is shown a round cast-iron boiler. This type of boiler is the most common type used for heating residences and small buildings. It consists of several castings placed horizontally one

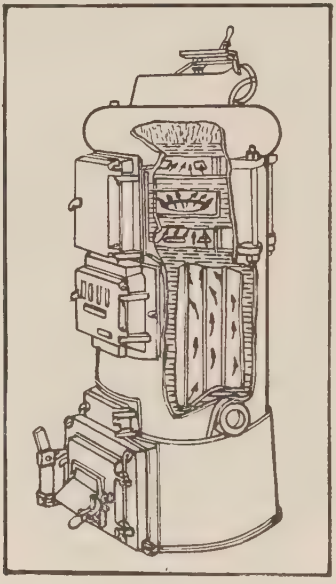


Fig. B-1-1. Design of Round Cast-Iron Boiler

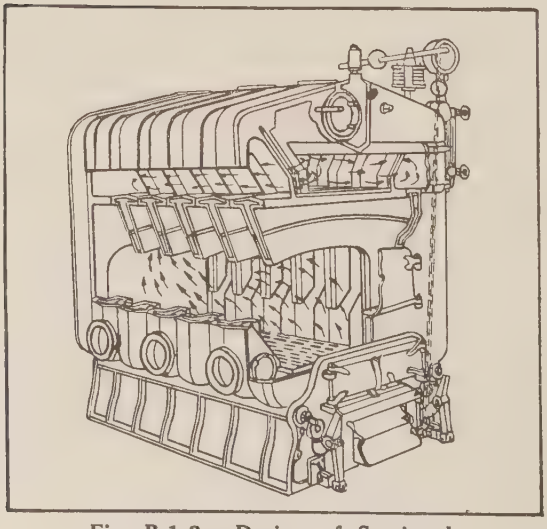


Fig. B-1-2. Design of Sectional Cast-Iron Boiler

on top of the other. Those sections, which are hollow and filled with water, are assembled with push or screw nipples and long bolts to pull and hold the sections together. Push nipples are accurately machine-turned and provide a water-tight metal-to-metal joint. The grate area for a round boiler, of course, is fixed, while the heating surface for a given diameter may be varied within certain

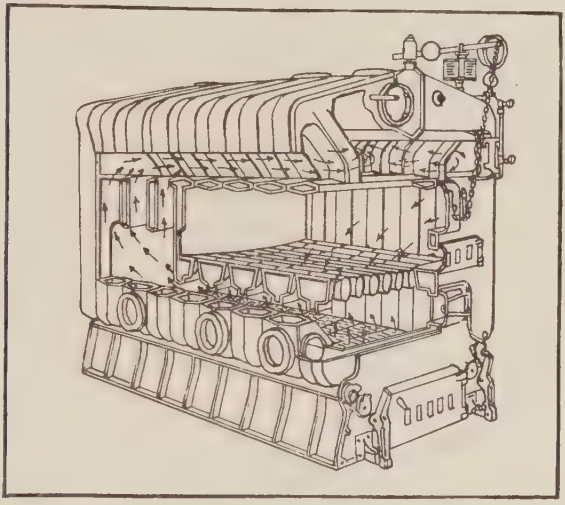


Fig. B-1-3. Design of Sectional Cast-Iron Down-Draft or Smokeless Boiler

limits, depending upon the number and size of the heating sections used in the assembly.

In Fig. B-1-2 is shown a sectional cast-iron boiler. This type of boiler may consist of from five to ten or more sections, joined with nipples. In the larger sizes, the sections are made in two parts to facilitate transportation and erection.

Work Problem B-1-7

In Fig. B-1-3 is shown a sectional down-draft boiler. This type of boiler is built primarily for burning soft coals without smoke, hence the name "smokeless," which is often given a boiler of this kind. Such a boiler has special furnace construction. The furnace includes two grates, instead of one, as found in the ordinary boiler. These grates are placed one above the other. The upper grate

is called a water grate since the grate-bars are made hollow and the water in the boiler circulates through the casting, thus preventing damage to the grate.

The fuel is fed onto the upper grate only. Air instead of all passing upward through the fuel bed, as in the ordinary type, enters at the top and passes downward through the fuel-bed. Combustion is most active at the bottom of the fuel-bed. The volatile gas in the fuel, being freed on the top of the bed, passes down through incandescent fuel where it is ignited.

On the lower grate there exist, practically continuously, small pieces of coke which have fallen through the upper grate and, being constantly replenished from above, present always a glowing bed of fuel. Thus the space between the two bars is maintained as an exceedingly hot combustion chamber, and presents a most suitable condition under which the descending volatile gas from the fuel bed above may mingle with hot air, which enters through the lower grate, and thus promote a high degree of combustion efficiency and assure practically smokeless combustion.

In general, it should be observed that exceptionally good draft and excellent chimney and flue construction are required for the smokeless type of boiler if best results are to be secured. Each manufacturer usually specifies the minimum allowable heights and areas or diameters of chimneys required or insisted upon.

In Fig. B-1-4 is shown a steel firebox boiler of the portable up-draft type, while Fig. B-1-5 illustrates a down-draft boiler of this same type. These boilers are assembled at the factory and are handled during installation as a complete unit. The grate and combustion chamber above it are surrounded by a water-jacketed firebox. Thus, a large amount of direct heating surface is exposed to the fire and gases of combustion. The portable firebox boiler of the smokeless type does not differ greatly from the up-draft portable firebox type, except in the number of grates and arrangement of combustion chamber. As with the cast-iron smokeless type, an inclined hollow-cast upper grate, filled

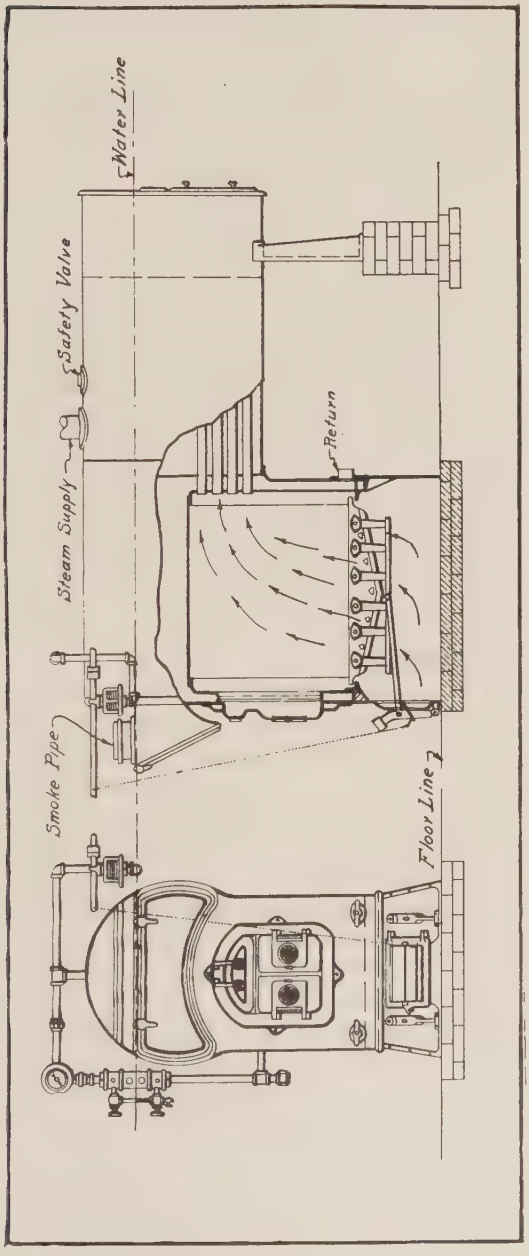


Fig. B-1-4. Steel Firebox Boiler of Portable Up-Draft Type

with water, is provided above the ordinary lower rocking-type grate and excellent combustion is assured, as explained above, for the cast-iron type.

In Fig. B-1-6 is shown a steel, firebox boiler of the brickset up-draft type. Fig. B-1-7 illustrates the same type of boiler in the smokeless or down-draft pattern.

Work Problem B-1-9

The preceding steel heating boilers are constructed with riveted joints. Electrically-welded steel heating boilers are illustrated in Figs. B-1-8, B-1-9, B-1-10, and B-1-11. The boiler shown in Fig. B-1-8 is built especially for residence work. It is constructed on the same combustion principle as the boiler shown in Fig. B-1-11, described below. The boiler illustrated in Fig. B-1-9 is a direct-draft portable firebox welded steel boiler, while those illustrated in Figs. B-1-10 and B-1-11 are of the same type but embody the smokeless feature without the use of a double grate. They contain an intermediate firebrick arch or curtain with a circulating pipe filled with water which connects with the longitudinal water legs. This firebrick arch and pipe extend across the firebox. Openings are provided in the firebrick curtain through which the volatile gases from the freshly-fired fuel pass to meet and mingle with the higher temperature, and more nearly complete combustion from the live fire at the rear of the grate is obtained. In the type shown as Fig. B-1-10 the gases of combustion pass through a central flue to a front smoke-box and thence through the fire tubes to the rear smoke-box and to the smoke pipe and chimney. In the type shown in Fig. B-1-11, the central arch of boiler in Fig. B-1-10 is replaced by a lower row of fire tubes connecting the firebox tube sheet and the front tube sheet through which the gases pass to the front smoke-box, then back through the upper row of tubes to the rear smoke-box and chimney.

Work Problem B-1-10

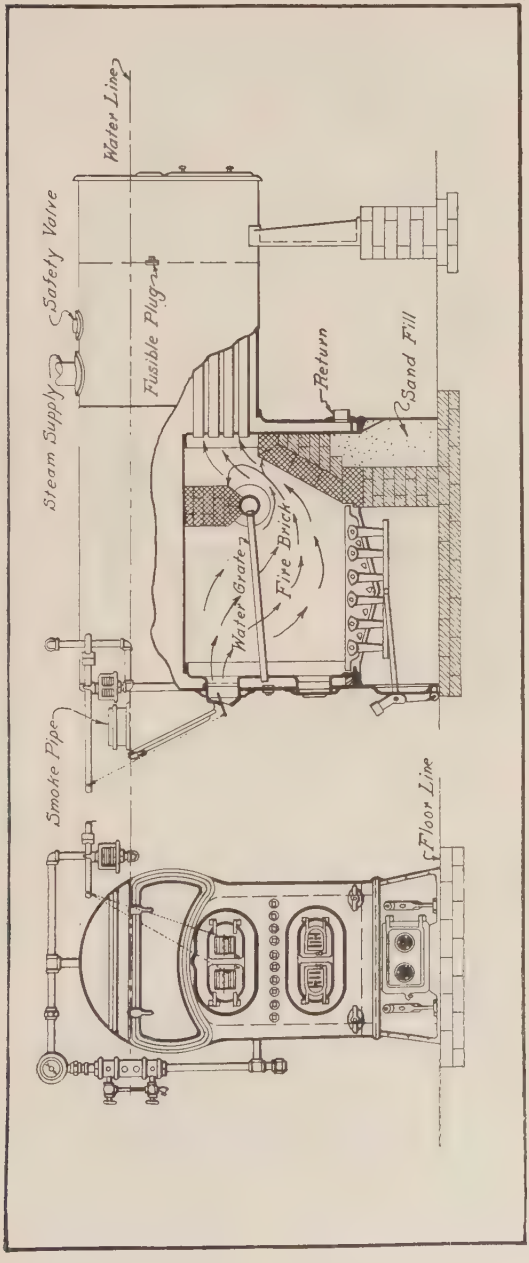


Fig. B-1-5. Steel Firebox Boiler of Portable Down-Draft Type

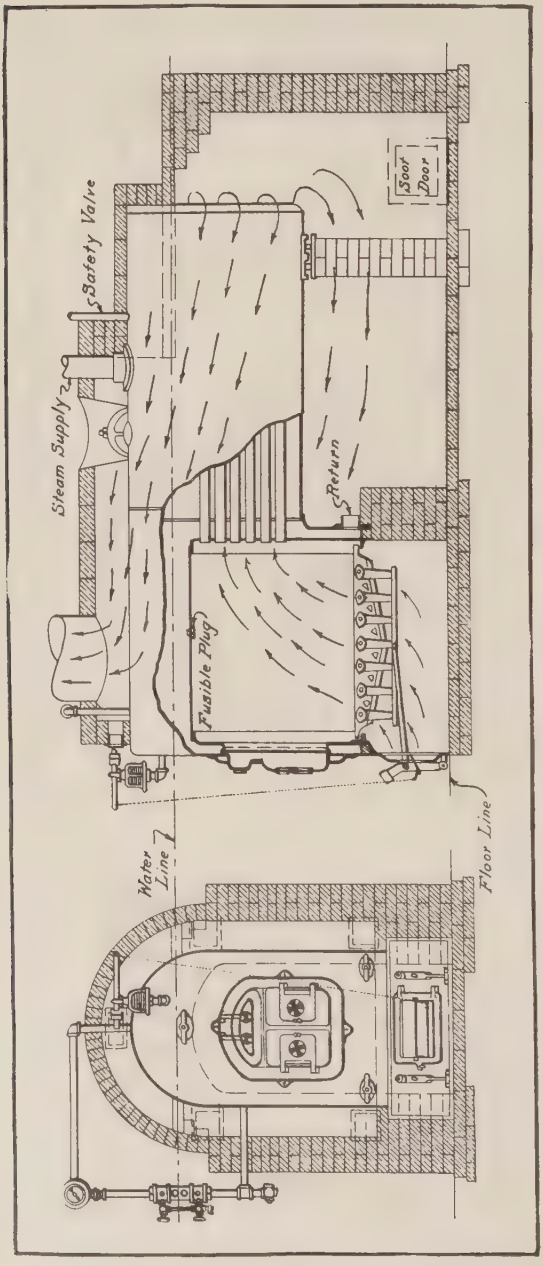


Fig. B-1-6. Steel Firebox Boiler of Brickset Up-Draft Type

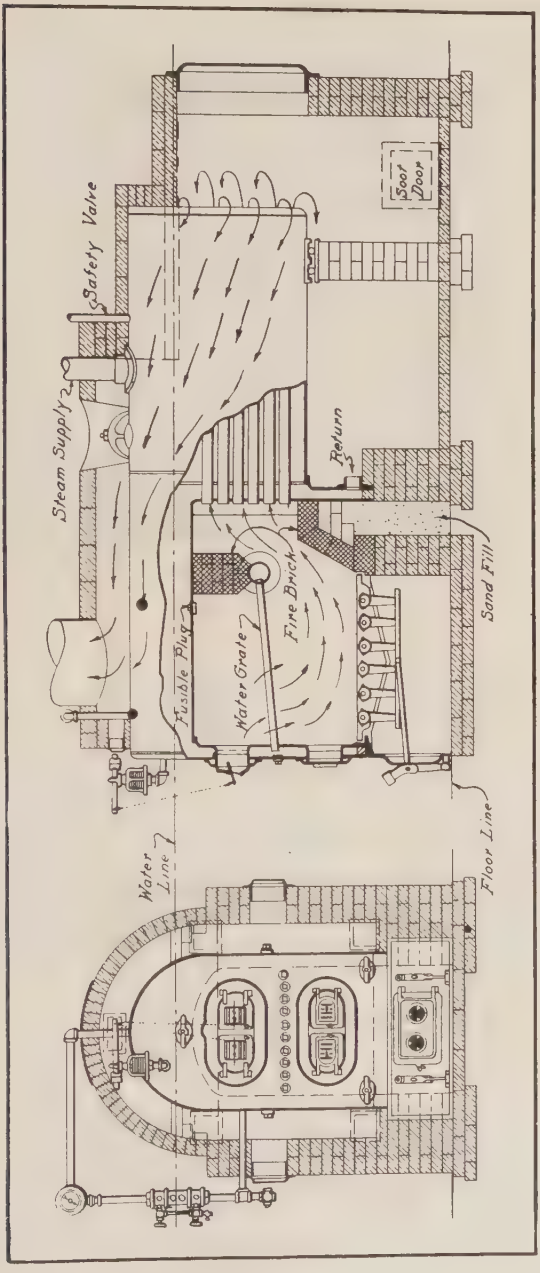


Fig. B-1-7. Steel Firebox Boiler of Brickset Down-Draft Type

RETURN-TUBULAR BOILERS

The boiler of Fig. B-1-9 and B-1-11 are really return-tubular boilers of the firebox type. Return-tubular boilers, however, generally are thought of as large steel cylinders provided with heads or "tube sheets" into which the fire-tubes are expanded and with the furnace exterior to the boiler, it being constructed directly below the front third of the shell. The shell is enclosed in a brick-setting. (See Fig. B-1-12.) The gases thus pass first to the rear along the bottom part of the shell, are then turned back by the boiler setting and returned through the fire tubes to a front smoke-box and then to the up-take and chimney. This type of boiler is built as a high-pressure boiler for operation at 100 lbs. per sq. inch and higher when specified. It is seldom considered for heating service until boiler requirements exceed 3000 sq. ft. of direct radiation.

Work Problem B-1-11

WATER-TUBE BOILERS

While the steel heating boilers, shown in preceding illustrations, are of the fire-tube design, so-called because the gases from the fire pass through the tubes, there are also types, both in the cast-iron and steel patterns, in which tubes or hollow castings are filled with water and the gases circulate around the outside instead of passing through. Thus the name water-tube boiler. They are built for supplying water or steam radiation.

Work Problem B-1-12

COIL WATER-TUBE STEEL BOILERS

In Fig. B-1-13 is shown a coil water-tube steel heating boiler. It is available for coal, oil or gas burning, and is built for furnishing steam or water to heating systems and for hot water supply to faucets for domestic laundry or similar uses.

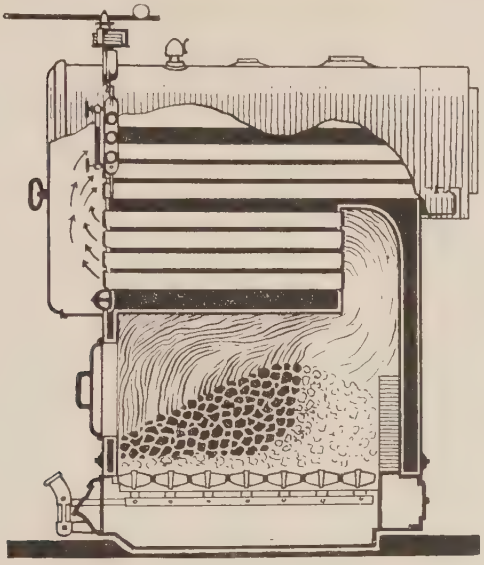


Fig. B-1-8. Electrically-Welded Steel Boiler, Residence Type

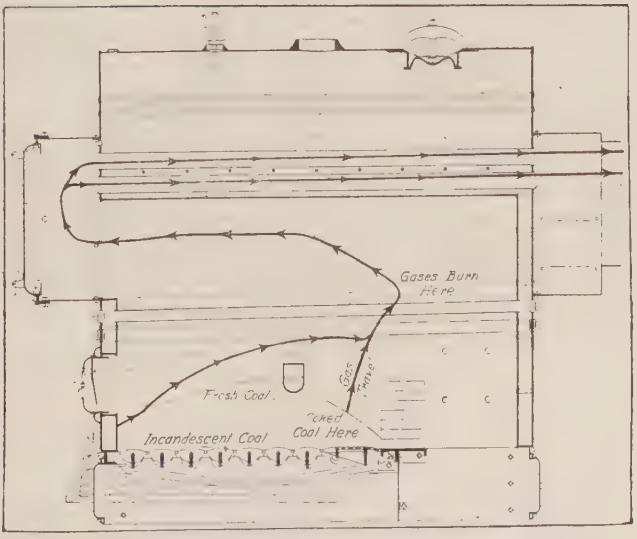


Fig. B-1-10. Portable Firebox Welded Steel Boiler, Smokeless Type

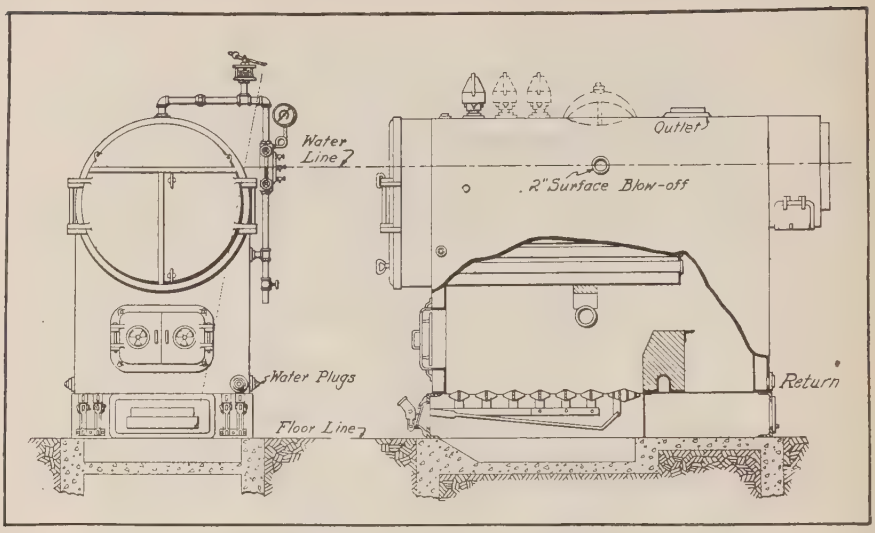


Fig. B-1-11. Portable Firebox Welded Steel Boiler with Smoke-Consuming Arch

Fig. B-1-9 referred to but not shown embodies the smokeless feature employing a double grate; otherwise, identical in every respect with the exception of the smoke-consuming arch.

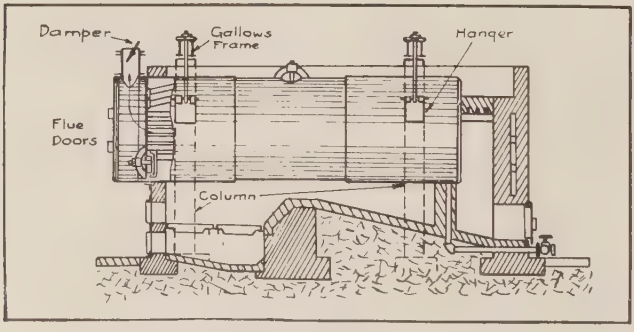


Fig. B-1-12. Brickset Return-Tubular Boiler

GAS-FIRED BOILERS

In Fig. B-1-14 is shown an equipped gas boiler suitable for natural or manufactured gas, while Fig. B-1-15 illustrates the construction of this boiler. It consists essentially of series of water tubes

having thin walls exposed to the heat of combustion. Each section of tubes is provided with an individual burner. The iron sections are assembled with cast-iron nipples and held by tie-rods. This type of boiler is metal jacketed and effectively insulated. It is built for steam, vapor and water heating system service and also for use for storage or automatic hot water supply service.

Work Problem B-1-13

BOILER HEATING SURFACE

Boiler heating surface is considered as direct or indirect surface. Direct heating surface is designated as that surface which receives the direct heat rays from the fire. Indirect heating surface is that surface which is in contact with the flue gases only. As the name implies, direct heating surface is the more effective and hence more valuable in a boiler. Both direct and indirect heating surface must have water on the side opposite to that where heat is applied. Heating surface is expressed in square feet.

The duty of a boiler is to transmit the heat in the fuel consumed to the water. Hence the capacity or ability of a boiler to do this depends upon the amount of heat transmitting surface in contact with the water in the boiler on the one side, and the fire and hot gases on the other side, and upon the temperature difference between these two sides. Rapid circulation of the water on one side and the heat on the other side is important. Preferably, this circulation should be in opposite direction. Heat absorption in heating boilers should be expected to vary from 1800 to 2400 B.T.U. per square foot per hour.

Work Problem B-1-14

BOILER GRATE SURFACE

Boiler grate surface is that surface on which the fuel is placed to be burned. It is the horizontal area occupied by the grates and is expressed usual-

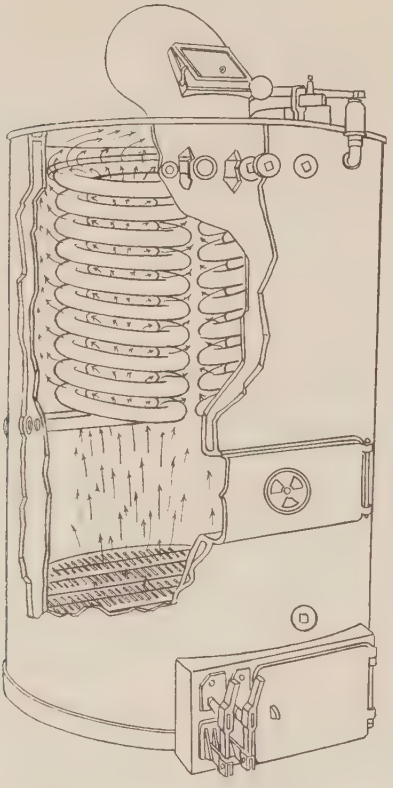


Fig. B-1-13. Coil Water-Tube Steel Heating Boiler

ly in square feet, although it may be given in square inches. Grate surface is an important consideration and should be checked in the selection of a heating boiler. There is a maximum rate at which coal can be burned in a given boiler under given conditions of installation, and where the total heat loss to be supplied by the boiler has been determined with care, and a knowledge of combustion rates is had, proper boiler selection becomes, at once, better assured.

Work Problem B-1-15

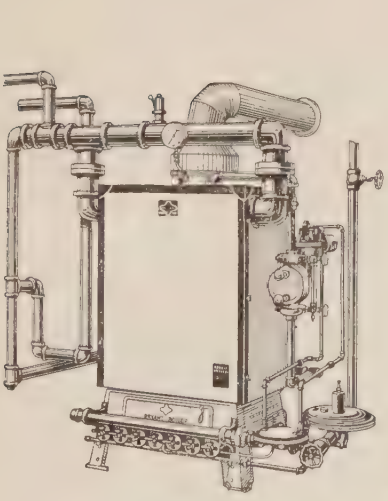
RATIO—H. S. TO G. S.

The ratio of heating surface to grate surface is a term that is frequently used when considering and studying boiler requirements and operation. It is merely a number representing the quotient obtained by dividing the actual heating surface in square feet by the grate area in square feet.

Work Problem B-1-16

FIRE-POT CAPACITY.

The capacity of any fire pot from grate level to middle of fire door should be ample to hold the amount of coal required for at least an 8-hr firing period, plus at least 20% reserve for use in igniting a fresh charge.



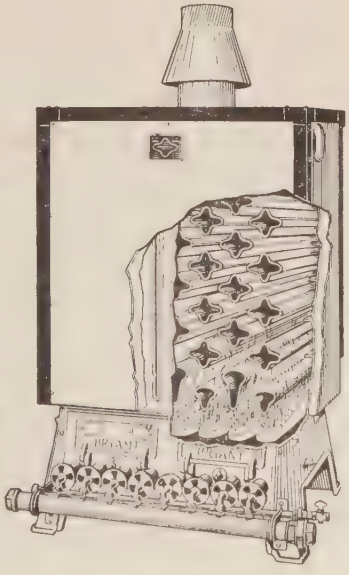


Fig. B-1-14 (at left). Typical Gas-Fired Boiler

Fig. B-1-15 (at right). Construction Features of Gas-Fired Boiler

The required depth for a given fire pot may be determined as follows:

First: Estimate the rate of combustion by reference to Table B-1-1 and multiply this by area of grate in square feet.

Second: Multiply product obtained under First by the desired firing period in hours and obtain weight of one fuel charge (not including reserve fuel).

Third: Multiply result under Second by 1.2 and obtain total weight of one charge (including 20% reserve for igniting fresh charge).

Fourth: Multiply average area of fire pot in square feet by the weight of fuel per cubic foot. Use 50 lbs. for anthracite and 40 lbs. for bituminous.

Fifth: Divide result Third by result Fourth and obtain the depth of fuel bed in feet for the given fire pot.

Work Problem B-1-17

FIRING PERIOD

The firing period in hours permitted for a given fire-pot may be estimated as follows:

First: Multiply average area of fire-pot by the weight of fuel per cubic foot.

Second: Multiply result First by depth of fire-pot in feet.

Third: Multiply grate area in square feet by the rate of combustion and the product obtained by 1.2.

Fourth: Divide result Second by result Third and obtain the firing period in hours.

Work Problem B-1-18

COMBUSTION CHAMBER VOLUME

The combustion chamber volume is the actual volume expressed in cubic inches (or cubic feet) of the space within a boiler in which combustion may occur. If insufficient for the fuel burned combustion is impaired, the gases do not have enough space to unite with the proper amount of oxygen

and expand to develop full heat of combustion, with the result that overall operating efficiency is low.

Work Problems B-1-19, B-1-20

Table B-1-1. Average Rates of Combustion for Steam and Water Boilers. (Safe Increase 10%)

FURNACE SIZE	SMALL	MEDIUM	LARGE
Grate, square feet	6 or less	6-10	10 or over
Coal per hr. per sq. ft., pounds	5	5.7	6.6
Run on one firing with 20% reserve, hours	8	7	6

PART B

STEAM AND WATER BOILERS

LESSON 2.

Chimneys and Flues

CHIMNEYS.

Nothing contributes more to successful boiler operation than a proper and suitable chimney, and nothing can affect the operation of an otherwise correct heating installation more detrimentally than a chimney that fails to fulfill its functions.

Primarily, the functions of a chimney are twofold. They are, (1) to provide suitably for discharging the wholly or partly-burned gases from the boiler so that they will not be harmful or objectionable, and (2) to assure the production of a draft sufficient to maintain a rate of fuel consumption economically consistent with heating demands.

Blame for an unsatisfactorily-heated structure is often laid upon the boiler installed. The heating contractor not infrequently is accused of having used an undersize or inefficient boiler when the fault lies entirely with the chimney. And it is a pity that so often the heating contractor is in-

capable of explaining and demonstrating the effect of chimney action on boiler operation. It is essential, therefore, that the relation between chimney and boiler be understood and it be realized that the design, location and construction of the chimney and flue are the keystones on which the successful fulfillment of a heating contract guarantee rests.

The ideal and most efficient chimney is built vertical with round flue and smooth interior surfaces. Such a flue offers least resistance to the ascending column of smoke and gases and, consequently, is more efficient than a flue with square or oblong cross-section.

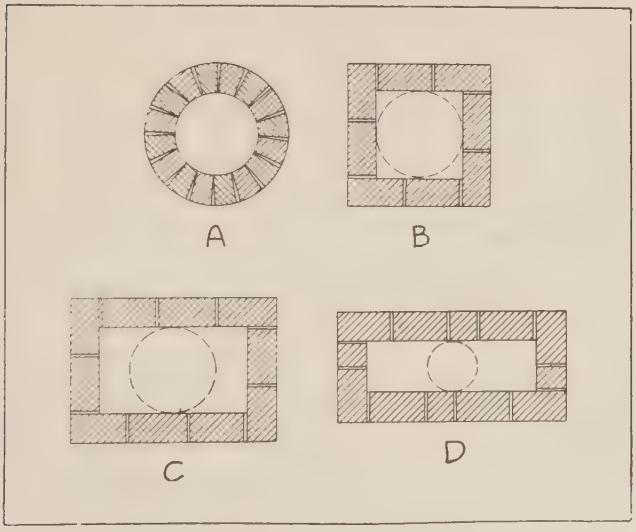


Fig. B-2-1. Types of Chimney Construction

EXAMPLES OF CHIMNEY SHAPES

Four examples of chimney construction are shown in Fig. B-2-1. The round chimney shown at A is seldom found in residential or medium-size buildings since it is more costly and the erection more difficult than that of a square or oblong chimney. The square chimney shown at B is next to be preferred to the round. It must have greater area than the round for the same capacity. It offers

greater resistance to the passage of the smoke and gases. The next preferable shape is shown at C as an oblong chimney. This type, perhaps, is most frequently used, since the brick work can be handled quite advantageously. Effectiveness of an oblong chimney decreases rapidly as the difference between its length and width increases. Therefore, the use of a chimney with length in excess of 4 in. greater than the width should be questioned. The type shown at D represents poor chimney construction. Friction losses are high and capacity correspondingly low. Chimneys of these proportions always should be avoided.

Work Problem B-2-1

FLUE LININGS

All chimneys should have lined flues. The use of flue linings reduces the fire hazard and affords improved draft conditions. Dimensions for rectangular and round fire-clay linings have now been standardized by the Eastern Clay Products Association.* In arriving at the standardization adopted, the association was guided by the sizes of common and face brick.

Standard sizes of rectangular fire-clay flue linings are shown in Fig. B-2-2, while Fig. B-2-3 shows standard sizes for the round linings.

Flue linings should be made of fire clay and specifications should read "fire-clay flue lining." It is a mistake to call for or permit the use of "flue-tile," "terra-cotta" flue lining, "clay" flue lining, "burned clay" flue lining or any similar product. Fire-clay flue lining is superior for chimney construction since it is made of a special mixture of clays thoroughly burned to withstand fire and heat, sudden or slow changes in temperature and all actions resulting from fire, smoke, gases or acids. It does precisely what unprotected mortar joints fail to do.

Work Problem B-2-2

*"Flues and Flue Linings—Chimneys and Fireplaces." Price $1.00, contains valuable information on chimneys and flues.

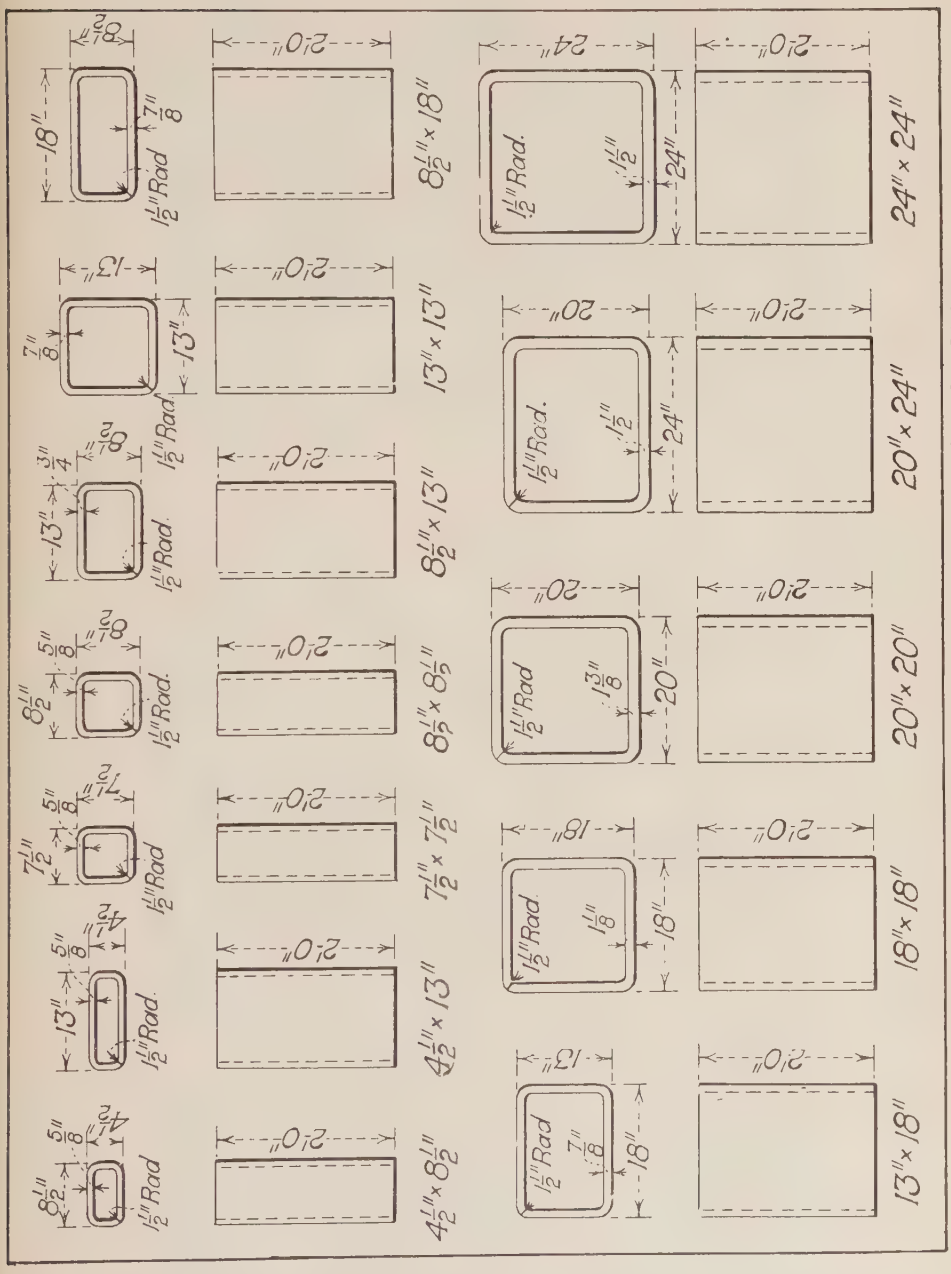


Fig. B-2-2. Standard Sizes of Rectangular Fire-Clay Flue Linings
(Eastern Clay Products Association)

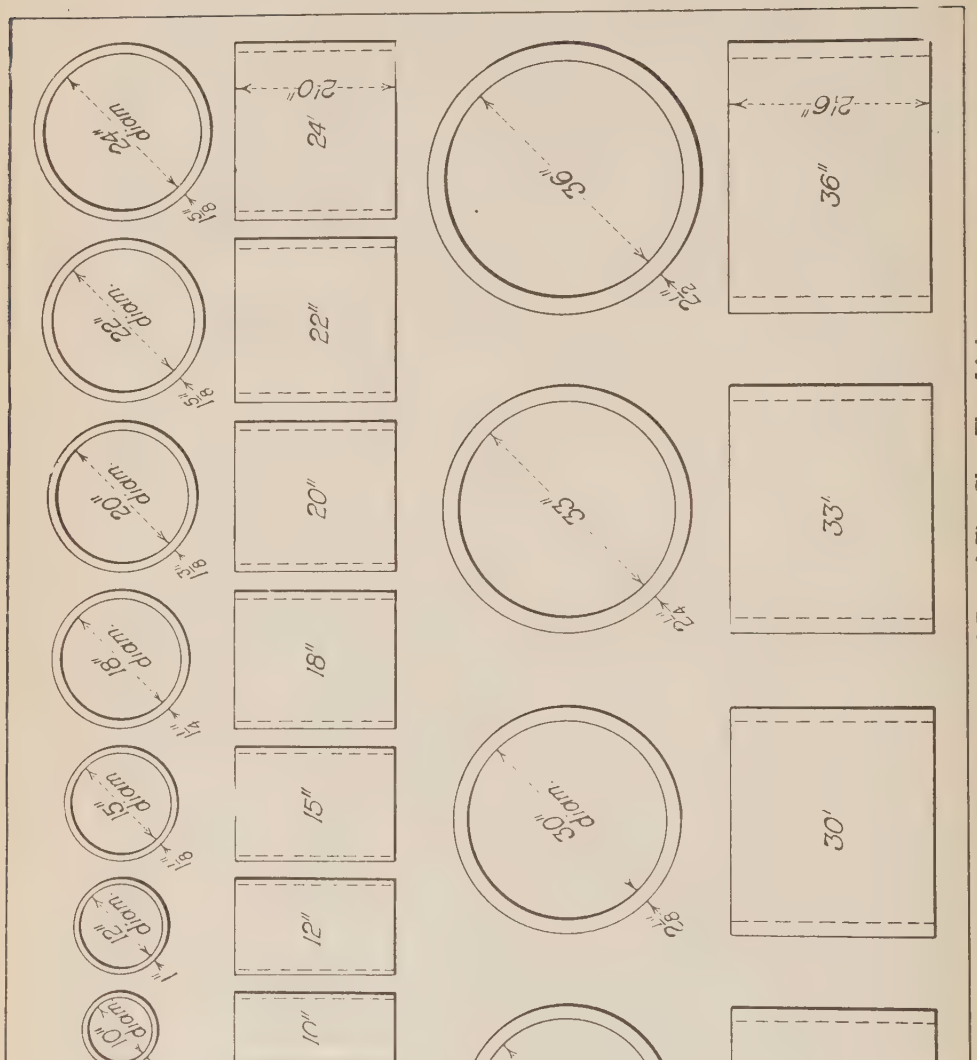

6" 8" 10" diam. 12" diam. 15" diam. 18" diam. 20" diam. 22" diam. 24" diam.
12" 15" 18" 20" 22" 24" 27" 30" 33" 36"
diam. diam. diam. diam. diam. diam. diam. diam. diam. diam.

Fig. B-2-3. Standard Sizes of Round Fire-Clay Flue Linings
(Eastern Clay Products Association)

FAULTY CHIMNEY CONSTRUCTION

Paradoxical as it may seem, a faulty chimney practically always shows its shortcomings through its effect upon some other feature of the plant. The fact that a lighted newspaper thrust into the bottom of a chimney will be sucked up and consumed with a roar is often erroneously taken to indicate a good draft. And because of this seemingly good "pull" the owner and general contractor often will emphatically insist that the draft is good. There is only one way to know whether the draft is good and that is to measure it. And the only proper way to measure it is by means of a suitable draft gage. Such an instrument is indispensable to every real, actual, virtual, or so-called heating engineer or contractor.

DRAFT

Before familiarizing the student with the use of the draft gage, let him first understand what draft is, what causes it and why it is essential.

Draft is a current of any sort. In a chimney flue, it is a current of smoke or products of combustion flowing from an enclosed or confined space into an open space or the atmosphere. The flow or movement is caused by the difference in pressure that exists in the confined space and that existing in the open space. This pressure difference is due to the fact that the weight of unit volume of a gas depends upon its temperature. For example, 1 cu. ft. of dry air at a temperature of 0° F. weighs 0.08636 lb. whereas the same air at a temperature of 300° F. weighs only 0.05225 lb.

Work Problem B-2-3

If the boiler-chimney system shown in Fig. B-2-4 is considered as immersed in the atmosphere, then the pressure exerted on each square inch of surface will be equal to atmospheric pressure, commonly taken at 14.7 lbs. per square inch. This pressure, as indicated, acts in the combustion chamber through the chimney, as well as through the ashpit,

and so long as there is no fire in the boiler, air temperatures within and without are the same, no pressure difference exists, and hence there is no draft and the levels in all U-tubes (explained later) are the same.

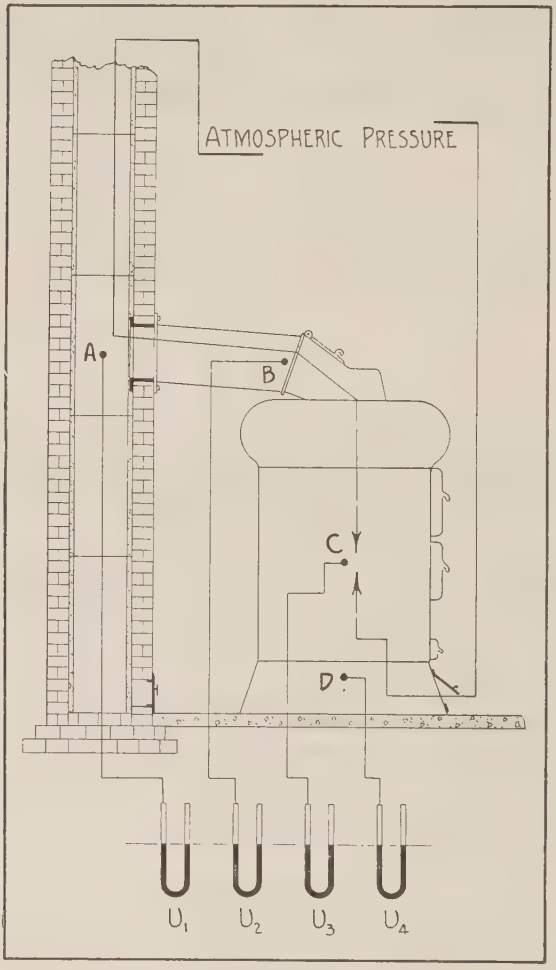


Fig. B-2-4. Boiler-Chimney System

With a fire in the boiler, conditions are quite different. In Fig. B-2-5, there is illustrated diagrammatically how draft occurs. At A, V_1 and V_1 represent equal volumes of air (1000 cu. ft.), each

having a temperature of 0° F. If containers are assumed weightless and flexible and the weightless rigid bar MN, resting on knife edge K, supports the two volumes on frictionless bearings, then each of the assumed volumes will exert the same pressure, 86.36 lbs. at the same distance from support and thus be in equilibrium so there will be no tendency of movement in either direction. This is the condition that exists in a cold boiler-chimney system with the temperature the same inside as outside the flue.

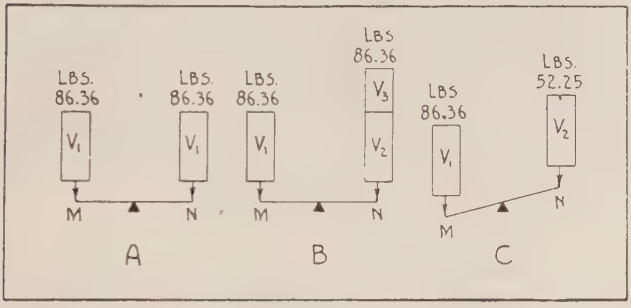


Fig. B-2-5. Relative Weights of Equal Volumes of Air at Different Temperatures

If the temperature of one of the V_1 volumes be raised to 300° F., its volume will increase from 1000 cu. ft. to approximately 1600 cu. ft., as represented by volume V_2 and V_3 at B of Fig. B-2-5. Thus the weight of unit volume has been decreased on the hot side since 1 cu. ft. of gas at 300° F. weighs only 0.05225 lb. as compared to 0.08636 lb. at 0° F. The weights on the two sides are the same unless the increase of volume on the hot side is allowed to escape.

If this is assumed to happen, the result will be as shown at C, Fig. B-2-5 where the 1000 cu. ft. of air or gas at 0° F., weighing 86.36 lbs. overbalances the 1000 cu. ft. at 300° F., weighing 52.25 lbs. and there is a tipping of the bar. A condition of unbalanced pressure exists and the lighter volume V_2 is pushed upward.

By considering the bottom end of container V_1 as connected to the ashpit of a boiler and the upper end of V_1 opened to the outside atmosphere, while

the bottom of container V_2 is connected to the smoke pipe of the heater, with the upper end opened to the outside atmosphere, there would be a tendency to movement down the V_1 side, through the heater and up the V_2 side. This flowing tendency is the draft and, as explained, is caused by the difference in weight between a volume of air on the outside of the chimney flue and an equal volume of products of combustion from the fire on the inside.

Thus, this condition of unbalanced pressure at the base of the stack persists so long as the temperature of the air and gases that enter the heater is raised therein. This is the basic principle which governs chimney action and upon which the draft depends. The greater the difference between the temperature in the flue and that outside, the greater the persistency of unbalanced pressure and hence the better the draft.

Work Problem B-2-4

THE U-TUBE

Fig. B-2-6 shows a U-shaped glass tube open at both ends A and B. A double scale, fitted to a thin

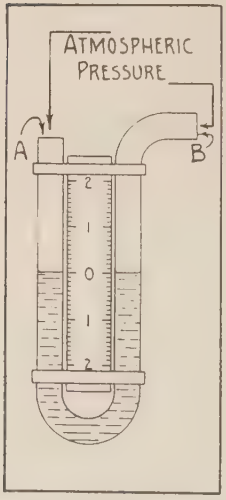


Fig. B-2-6. Construction of U-Tube

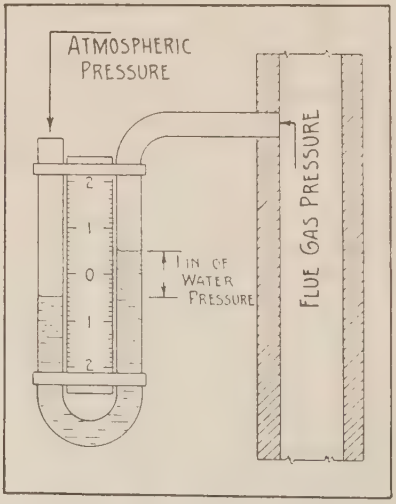


Fig. B-2-7. U-Tube Connected to Chimney Flue

piece of wood and mounted as indicated, is graduated in inches and in tenths of an inch. The glass tube is often about ½ in. in diameter. It contains just sufficient water so that when the tube is held in a vertical position, with each end open to the atmosphere, the level of the water in the two sides will agree with the zero on the scale. Such an instrument is called a U draft gage.

If the end B of such a gage is connected, as indicated in Fig. B-2-7, into a chimney flue up which hot gases are passing and the end A is open to the atmosphere, the pressure of the colder and heavier atmosphere will cause the level of the water to rise in one leg and lower a corresponding amount in the other leg. The difference in elevations of the two water levels is an exact measure of the draft. The position of the levels in Fig. B-2-7 indicates a draft of 1 in. of water.

Work Problem B-2-5

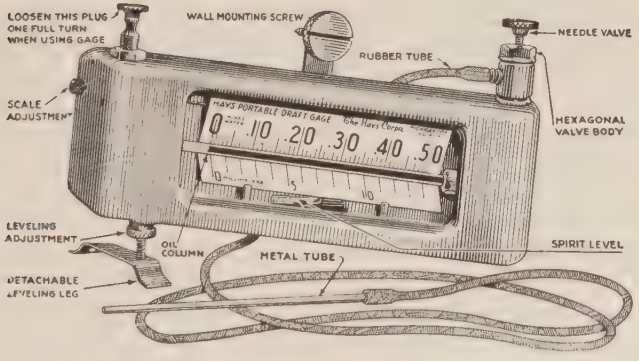


Fig. B-2-8. Portable Draft Gage
(Courtesy The Hays Corporation)

THE DRAFT GAGE

The principle of the U-tube is used in all draft gages. Various designs are available. They have been developed because draft intensities in most chimneys are very low, from 0.01 to 0.20 in. of water and it is very difficult and practically impossible to determine with accuracy these small differences in level by means of the ordinary U-tube.

Standard draft gages, therefore, are usually made with one inclined leg with a tube of small bore filled with a liquid which is lighter than water. Thus the difference in level will be magnified and more accurate reading is assured. Graduations are made so that the readings indicate inches of water exactly as with a U-tube. Care must be exercised in the use of a draft gage, else results may be questioned. Complete instructions are contained in the literature of draft gage manufacturers. A gage of the portable type, readable to 1/100 in. is illustrated in Fig. B-2-8.

Work Problem B-2-6

Air pressure, as explained with reference to D of Fig. B-2-5, will force air into the ashpit of the boiler, up through the grates and fuel bed into the combustion chamber. A definite quantity of air must be supplied to the fire or the required amount of fuel cannot be burned. Hence, the quantity of air forced through the fuel bed really governs the rate of combustion. Air flow is controlled by pressure difference and this by the frictional resistance of grates and fuel bed. If this resistance is to be constant (and it may be considered practically so for a given boiler) then the pressure difference is the sole controlling factor. This is registered by the draft gage. Hence the draft gage reading may indicate the rate of combustion to be expected from a given boiler-chimney system.

In order to consume a given quantity of fuel on the grates of an average boiler under usual operating conditions, there is required a pressure difference on the two sides of the fuel bed, that is, in the ashpit and in the combustion chamber, of approximately 0.01 in. of water per pound of coal burned per square foot of grate per hour. Thus, if heating demands require a combustion rate of 5 lbs. of coal per hour per square foot of grate, the difference in draft intensity between ashpit and combustion chamber must be 0.05 in. of water.

Work Problem B-2-7.

Under definite temperature conditions, a flue of a given height will produce a certain intensity of draft. When the flue is a part of a boiler-chimney system, there are five principal factors that affect the degree of intensity—(1) the resistance to upward flow of the gases in the chimney due to their rubbing against the sides (frictional resistance) and the cooling effect of the chimney, (2) the fric-

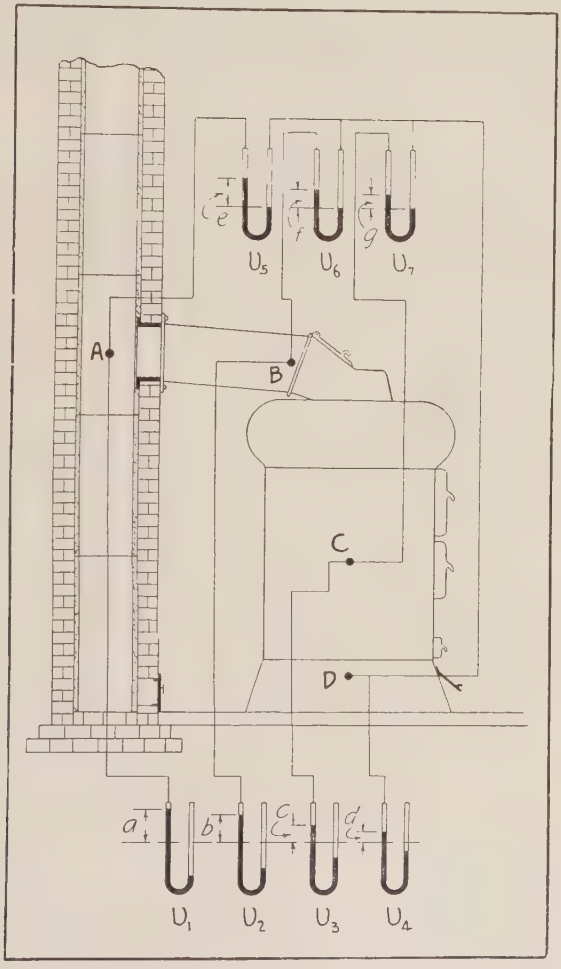


Fig. B-2-9. Draft Losses Through Boiler

tional resistance in the smoke pipe, (3) the resistance to flow through the passages of the boiler, (4) the resistance to the passage of air and gases

through the grate and fuel bed, and (5) the resistance to air flow into and through the ashpit. All these factors act to lessen available draft intensity.

Work Problem B-2-8.

Reference to Fig. B-2-9, showing a diagrammatic view of a boiler connected to a chimney flue, the top of which is assumed to be 45 ft. above the grate level, and the following will show how draft losses occur.

For the sake of clearness, draft gages have been shown as U-tubes rather than of the inclined type. Locations A, B, C and D have been selected as points through the boiler-chimney system at which it is desired to know the intensity of draft and to observe how draft losses occur.

Location A is in the flue at the point where the smoke pipe enters; location B is at the smoke-pipe-heater connection; location C is in the combustion chamber just above the fire and location D is in the ashpit just below the grate.

For the time being, it will be assumed that the U-tube draft gages marked U_1, U_2, U_3, and U_4 are the only ones connected at points A, B, C, D. Each of these has one leg connected to the respective point while the other is open to the atmosphere.

By making certain assumptions, there can be established the theoretical draft which this chimney will produce if no frictional losses occur. Then if the intensity be measured at different points, the total loss due to these resistances may be determined and the actual draft available for operation found. If the products of combustion enter the chimney at 400° F. and in their upward passage cool to 300° F. before leaving at the top, the assumed average flue temperature will be 350° F. Based on this average temperature within the flue and a 0° F. temperature for the outside air, this chimney should produce a theoretical draft of 0.25 in. of water. The formula by which this may be calculated is given at the bottom of Table B-2-1.

Work Problem B-2-9.

Theoretically, if one leg of draft gage U_1 were connected to location A and the other open to the atmosphere, the difference in elevation of the water in the two legs would read 0.25 in. A gage so connected, though, would indicate a value slightly less, owing to the frictional resistance of the flue and its cooling effect. With the gage U_1 graduated to read directly in inches of water, the distance *a* on U_1 may be assumed to read 0.23 in. of water.

TABLE B-2-1. CHIMNEY DRAFT INTENSITIES, INCHES OF WATER

(Values taken at 0.80 of theoretical)

Height of chimney, ft.	Average Temperature of Flue Gases, Deg. F.						
	200	225	250	275	300	325	350
20	0.07	0.08	0.09	0.10	0.10	0.10	0.11
25	0.10	0.10	0.11	0.12	0.13	0.13	0.15
30	0.11	0.12	0.14	0.14	0.15	0.16	0.17
35	0.13	0.14	0.15	0.16	0.18	0.18	0.19
40	0.15	0.16	0.18	0.18	0.20	0.21	0.22
45	0.17	0.18	0.20	0.21	0.22	0.23	0.25
50	0.19	0.20	0.22	0.24	0.25	0.26	0.27
55	0.21	0.22	0.25	0.26	0.27	0.29	0.30
60	0.23	0.24	0.27	0.28	0.30	0.31	0.33

Formula for theoretical draft: $H = 7.64h \frac{1}{Ta} - \frac{1}{Tc}$

H = total head produced by chimney, inches of water.
h = height top of chimney above grate, feet.
Ta = absolute temperature of air = 10° F. plus 460° F.
Tc = absolute average temperature of chimney gases = average temperature plus 460° F.

Passing next to U_2, a still lower reading will be registered which, designated as *b*, properly may be assumed 0.225 in. of water. This difference of 0.005 in. of water between locations A and B is caused by frictional resistance in the smoke-pipe.

Between locations B and C, a greater loss of draft intensity may be expected, so U_3 may be assumed to read 0.200 in. of water, represented by C, or to indicate a loss of 0.025 in. of water between B and C. Again in similar manner, the draft intensity reading on U_4 for location D, and shown as *d*, may be read as 0.190 in. of water, indicating a loss of draft through the grate and fire of 0.010 in. of water.

TABLE B-2-2. DRAFT INTENSITIES AND LOSSES

Draft Available, In. of water		Draft losses, In. of water	
Theoretical	0.25	In flue	0.020
At smoke-pipe entrance to flue	0.23	In smoke-pipe between B and A	0.005
At smoke-pipe entrance to heater	0.225	Through combustion chamber between C and B	0.025
In combustion chamber	0.200	Through grate and fire between D and C	0.010
In ashpit	0.190		
		Total loss	0.069

Thus, draft intensity to be expected, owing to losses, will be 0.190, instead of 0.25 in. of water, as theoretically computed.

In Table B-2-2, the various draft intensities and losses at different locations and between the several points are tabulated for ready reference.

TESTING THE DRAFT

Obviously, it is not always feasible to take draft gage readings at each location, as explained in connection with Fig. B-2-9. It is essential always to make at least one reading of the draft and this should be taken in the smoke-pipe just outside of the chimney.

Using a draft gage of the inclined type, care must be exercised to see that it is level before making readings. Each gage is fitted with a level for this purpose. A draft connection can be made by punching a small hole in the smoke-pipe and inserting therein a small metal tube connecting the outer end to the gage through rubber tubing. A zero reading of the gage should first be made with both ends of the gage open to the atmosphere. Then the check damper should be closed, the ashpit door opened and the fire in the boiler permitted to burn long enough to be assured that the combustion rate is as high as the chimney will produce before taking the reading.

In Fig. B-2-9, the draft gages marked U_5, U_6, and U_7 represent a differential gage. By the use of

a differential draft gage, the difference in draft intensity between the two points to which the two legs of the gage are connected is read directly. For example, gage U_5 has its left leg connected to location A while the right leg connection communicates with location D and the pressures existing at these respective points act on the two water surfaces.

If the pressures were equal, the water levels in each leg would agree, but since the draft intensity at A is greater than at D, there will be a difference in the two levels. If a movable scale be used and its zero mark be placed in line with the lower level, the loss in pressure between A and D will be indicated by the measurement of the difference in levels. Height *e* on gage U_5 would, in this case, read 0.060 in. of water, *f* on gage U_6 would read 0.035 in. of water, while *g* on gage U_7 would read 0.010 in. of water, all of which agree with the differences noted in Table B-2-2.

Work Problem B-2-10.

CHIMNEY TROUBLES

The required area for a flue depends upon the quantity of smoke or gases that it must pass and the velocity at which gases will flow upward. Reliable available data on the performance of chimneys are lacking, particularly as regards what takes place in the chimney itself. The variations of temperature, density, and draft from the top to the bottom for the various shapes and sizes of flues are practically unknown, so far as the writer is informed. The velocities and volumes throughout the length of the flue are not definitely known; the effect of the wind is not thoroughly understood, particularly with reference to air leakage into the chimney under heavy winds, its effect upon the cooling of the gases and to the suction effect that it may produce directly over the top of the chimney. All of these factors have an appreciable influence upon the size or area that may produce the best results and, until carefully-developed data on these features are available, recommended sizes only can be such as experience has shown to give good results.

Unquestionably the height of a chimney is one, if not the most important, factor in chimney design. It must be high enough, not only to be capable of producing sufficient draft, but to avoid the danger of air currents which may mar the draft (See A and B, Fig. B-2-10). The top of a chimney should

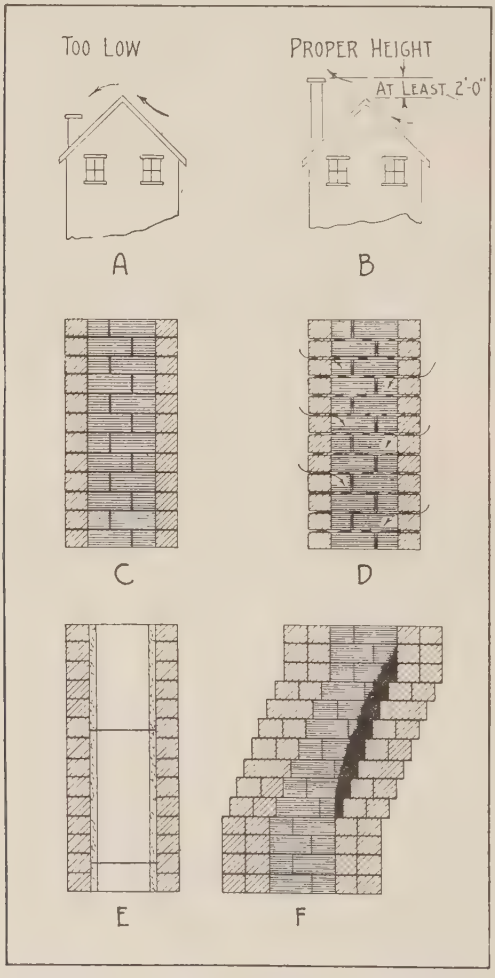


Fig. B-2-10. Examples of Bad Chimney Construction

extend 3 ft. above flat roofs and 2 ft. above the ridge of peak roofs. Extensions, if used to add height, should be properly fitted. If the joint be-

tween a brick and a metal extension is not tight, its service may well be questioned.

Unlined chimneys are a source of continual trouble. Frequently tight when first constructed, the heat and weather cause the mortar gradually to disintegrate so that air leaks in at the joints, with a consequent lessening of the draft. At C, Fig. B-2-10, is shown an unlined chimney before use, while at D its appearance after being in use is illustrated.

Offsets or bends in chimneys are likely to reduce the area or loose bricks, and mortar may fall into and lodge in such a way as to cause restrictions. (See F, Fig. B-2-10 and note how soot accumulation may cause restricted area.)

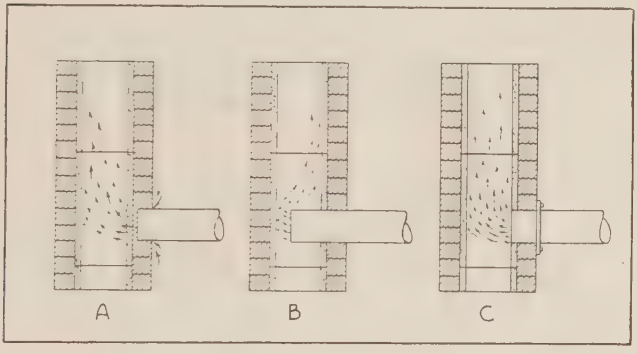


Fig. B-2-11. Incorrect and Correct Methods of Making Smoke-Pipe Connections

Careful installation of the smoke-pipe in the chimney is essential. Wrong methods are indicated at A and B, Fig. B-2-11. At A, the pipe does not set in far enough and an opening exists around the pipe. This opening acts as a check damper. The projecting pipe at B causes serious interference of gas flow. At C, the pipe is of proper length, has a cement-tight joint and close-fitting collar plate, assuring gas tightness and free unobstructed gas passage.

Openings into a chimney for other than the smoke pipe of the boiler should never be permitted if unsatisfactory draft is to be avoided. If a soot pocket is provided at bottom of flue, the clean-out opening should be equipped with a tightly-fitting

cover which should be always in place except when removed for cleaning soot accumulations.

Work Problem B-2-11.

SIZE AND HEIGHT OF CHIMNEY

The establishment of size and height of the chimney for a given installation properly demands consideration of the total heat demands, the type and number of boilers to be used, the fuel to be burned, and the character and altitude of the building. Therefore, the determination of size and height of chimney should be the last part of the heating design.

Various tables for chimney sizes have been prepared and are found in trade catalogs and the like. Reputable boiler manufacturers specify draft requirements for their respective boilers and usually give required flue areas, sizes and heights of chimneys.

Irrespective of whether the fuel to be used is coal, coke, wood or oil, the minimum effective area inside of the flue linings for any steam or water boiler should not be less than 70 sq. in. and the short cross-sectional dimension never should be less than six-tenths the greater dimension.

Work Problem B-2-12.

The quantity of smoke and gases to be handled by a flue depends on the quantity of fuel burned in a given time. Therefore, the combustion rate and area of grate should be known. Table B-2-3, recommended by the American Society of Heating and Ventilating Engineers for low-pressure heating boilers, embodies a consideration of influencing factors and represents conservative modern practice in the matter of chimney sizes.

Work Problem B-2-13.

The sizes of flues there given are based on run-of-mine soft coal, but may be used without reduction for other fuels. If screened coal, smaller than nut size of anthracite or coke is used, increased

TABLE B-2-3. CHIMNEY SIZES

Steam Boiler Capacity, Sq. ft. of Radiation	Hot Water Heater Capacity, Sq. ft. of Radiation	Nominal Dimensions of Fire-Clay Linings, In.	Rectangular Flue			Round Flue	
			Actual Inside Dimensions of Fire-Clay Lining, In.	Actual Area, Sq. In.	Effective Area, Sq. In.	Inside Diameter of Lining, In.	Effective Area, Sq. In.
590	973	8½ x 13	7 x 11½	81	70		
690	1140					10	79
900	1490	13 x 13	11½ x 11½	127	99		
900	1490	8½ x 18	6¾ x 16¼	110	100		
1100	1820					12	113
1700	2800	13 x 18	11½ x 16¼	183	156		
1940	3200					15	177
2130	3520	18 x 18	15¾ x 15¾	248	195		
2480	4090	20 x 20	17¼ x 17¼	298	234		
3150	5200					18	254
4300	7100					20	314
4600	7590	20 x 24	17 x 21	357	278		
5000	8250	24 x 24	21 x 21	441			

Height in feet from grates: As height necessary is dependent upon the draft requirements of the varying designs, these factors should be known before height can be determined accurately.

If the installation is located where the altitude exceeds 500 ft. above sea level, the height of the flue draft is required and the installation demands special consideration.

Increase height of flue by 10% for each 1000 ft. should be increased as follows:
above sea level and reduce the capacity by 5%.
determined as follows:

Work Problem B-2-14.

EFFECTIVE AREA

The effective area of a flue, broadly speaking, is the theoretical cross-sectional area which the column of smoke and gases rising with a spiral motion will occupy in the passage up the flue.

In a round lined flue, the entire area is considered effective area. In a square lined flue, the effective area is considered as equal to the area of a circle, the circumference of which is tangent to the inside surface of the flue or, in other words, side dimension of the flue.

The effective area of a rectangular lined flue is a circle whose diameter is equal to the shorter in-

First: Note the short inside dimension.
Second: Subtract the short inside dimension from the long inside dimension.
Third: Multiply result First by result Second.
Fourth: Multiply the short inside dimension by itself, and multiply the product thus obtained by 3.14.
Fifth: Divide result Fourth by the numeral 4.
Sixth: Add result Fifth to result Third, and obtain the effective area in square inches.

Work Problems B-2-15 and B-2-16.

If an existing flue is to be used or it is necessary to build a flue that is more than 100% in excess of the areas given in Table B-2-3, the chimney should be capped with stone terra-cotta, cast-iron or other approved material. The opening through the capping should be not more than 50% in excess of the required area.

Work Problem B-2-17.

When a battery of two boilers is to be used, the rated capacity of the flue should be taken at 60% that in Table B-2-3. Thus, if two boilers, each with a rated capacity of 1940 sq. ft. are to be used, the required effective area of a suitable round flue will be 354 (effective area) $\times$ 0.60 or 212 sq. in. Table B-2-3 indicates that a round flue of 20 in. diameter should be used.

Work Problem B-2-18.

If three boilers are to be installed, 40%, instead of 60% should be used; for four boilers, use 35%.

Work Problem B-2-19.

PART B.

STEAM AND WATER BOILERS

LESSON 3.

Capacities and Ratings

Capacities and ratings of boilers is a dangerous field for trespass, yet, no course of study that attempted to acquaint a student with a knowledge of heating, would be even partially complete without, at least, a superficial coverage of this most interesting, most important, most elusive, and most necessary part of heating work.

Happily, the task is made somewhat easier and the possibilities of the future considerably brighter for a unified understanding and consideration of boiler ratings and capacities since the adoption in June, 1927, by the American Society of Heating and Ventilating Engineers, of the report of its committee for Rating Low-Pressure Heating Boilers.

CAPACITIES AND RATINGS

Owing to the multiplicity of terms used in boiler catalogs for expressing the rating or capacity of

boilers, it is difficult for the student, or one who has not had intimate contact with performances of different boilers, to make a comparison of two or more—and much more difficult to make a safe selection.

Nothing, in the opinion of the writer, is more necessary to the heating fraternity than a common and universally applicable formula which will standardize boiler selection. Until such time as this is possible, the student should be on his guard and properly equipped with a knowledge of the meanings of boiler capacity and boiler rating to judge each on its merits.

BOILER HORSE POWER

Originally, boilers were built for power purposes. Hence, a boiler was rated in terms of horse power. A boiler horse power is the rate or energy required to evaporate (per hour) 34.5 lbs. of water at 212° F. into dry steam of 212° F.

If water, at a temperature of 212° F., is fed into a boiler and evaporated, that is, changed into steam having the same temperature and being under the same pressure as the water, evaporation is said to take place *from and at* 212° *F.*

Work Problem B-3-1

In practice, the feed water enters the boiler below 212° F. and the actual conversion into steam usually takes place at temperatures above 212° F. Thus, under operating conditions, the quantity of water actually evaporated would be somewhat different from that where temperature of water and steam were the same, namely, 212° F.

If the quality of the steam is known, that is, the per cent of moisture per pound, and the actual quantity evaporated or produced is known, then, by means of a steam table, the evaporation equivalent to what it would have been *from and at* 212° *F.* may be computed. If the quantity of coal fired during the time consumed in obtaining this equivalent evaporation were known, then the rate of equivalent evaporation per pound of coal *from*

and at 212° *F.* may be found by dividing the total equivalent pounds evaporated by the total pounds of coal fired. All quantities usually are expressed on an hourly basis.

This value for pounds of water which the boiler would evaporate from and at 212° F. is known as the *equivalent evaporation from and at* 212° *F.* and is the quantity by which horse power rating of a boiler is measured. Consequently, if the total equivalent evaporation per hour be divided by 34.5, the boiler horse power developed will be obtained.

Work Problem B-3-2

Capacities or ratings of power boilers therefore express quite exactly the measure of what the boiler will do under certain operating conditions.

LOW-PRESSURE HEATING BOILERS

The problem of the low-pressure heating boiler is quite a different matter. Up to the present time, there has been a vast difference in the ratings of the many low-pressure heating boilers due to the fact that no standard code has been adopted whereby the manufacturers could co-operate in such standardization.

Low-pressure boilers, either steam or water, usually are rated in terms of the number of square feet of standard cast-iron direct radiation standing in still air at 70° F. which the boiler is capable of supplying when the plant is operating under stable conditions and proper allowance has been made for the radiation load due to piping and connections.

Manufacturers' ratings of boilers are those values found in respective manufacturer's catalogs and express the measure of the performance of the particular boilers as placed thereon by each manufacturer. Such ratings sometimes are given for well-defined operating conditions; at other ratings, for what the manufacturer may assume to be average working conditions. Such ambiguity were best avoided.

BASIS OF BOILER RATINGS

Perhaps the most universally applied method for rating low-pressure boilers up to the present time is as follows:

For steam boilers: To base the rating on a gage pressure of 2 lbs. per square inch at the boiler and a condensation rate of 0.25 lbs. of steam per square foot of direct cast-iron radiating surface standing in still air at 70° F.

For water boilers: To base the rating on water leaving the boiler at 180° F. and a transmission rate of 150 B.T.U. per square foot direct cast-iron radiating surface standing in still air at 70° F.

Heating and Piping Contractors National Association stipulates that the effective rating of heating boilers shall be expressed in terms of square feet of direct radiation load (equivalent to 240 B.T.U. emission per hour per square foot of steam radiation, or 150 B.T.U. per hour for water radiation), as determined by the following formula:

$$\text{For steam boilers, output} = \frac{W \times H \times E}{240}$$

$$\text{For water boilers, output} = \frac{W \times H \times E}{150}$$

Where

W = average dry fuel burned per hour in pounds for period of the test.
H = heat value per pound of dry fuel in B.T.U.
E = efficiency of boiler.

While it might seem quite simple to establish a boiler rating from the above, there are other factors which influence those already mentioned. Few catalogs for low-pressure heating boilers contain all the data necessary to determine fully the suitability of a boiler for a particular installation.

Most boilers are selected on the basis of the ratings given in the catalog. Such ratings may be stated as "guaranteed ratings," yet, without knowing the pounds of coal burned per hour per square foot of grate surface when the rating was fixed, the stack temperature during the rating test and the number of hours the boiler is supposed to operate and maintain its rating on one charge of fuel, a full appreciation of the capacity of the boiler is lacking.

Thus, grate surface, fire travel, heating-to-grate-surface ratio, combustion rate, firing period, stack

temperature, draft at base of stack, size and height of chimney, combustion efficiency, condensation rate, and boiler efficiency, all contribute variable factors which have an effect upon the suitability of a particular boiler for a given service.

Work Problem B-3-4

In the preceding lesson, the subject of draft was considered. It should be realized that every boiler when installed works under given fixed conditions so far as the size and height of the chimney are concerned, and that this size and height of chimney determine the available draft. The available draft determines the rate at which fuel can be burned, while this combustion rate controls essentially the evaporation rate. The area of grate in square feet and the combustion rate definitely set the total fuel which can be burned during one hour, and the total fuel consumed in one hour together with the evaporation rate determine the total evaporation. The total evaporation establishes the measure by which the boiler may be said to be capable of supplying a definite amount of standing direct cast-iron radiation.

Thus, for one set of values for each of the above quantities, a definite rating might be assigned to the boiler. Change the value of any one of the factors and immediately the rating is affected.

Work Problem B-3-5

DETERMINING DEMANDS

Until such time as a definite and specific method of boiler selection is universally adopted, boiler capacity will be rated on the basis of the standing direct radiation or equivalent on the job for which the boiler will be installed.

In Part R of this course, devoted to Radiators and Radiation, the student was taught how to determine the area of radiators, steam or water, required to overcome or compensate for the heat loss from the room in question. In using radiation area as basis of boiler capacity, it must be remembered that before the heating medium reaches a radiator it must pass through pipes from which heat is radiated.

So, if a definite quantity of heat is required in the radiator, then sufficient additional heat must leave the boiler to provide for the loss from mains, branches, risers and all piping. Therefore, in order to assure ample boiler capacity, (1) the boiler capacity figured on radiator area above must be increased by some amount that will include safe allowance for piping, etc., or (2) the radiators should be reduced by an amount equivalent to the radiation supplied by mains, risers, returns, etc.

For rough approximation, an allowance of 25% to 50% in excess of the boiler capacity required for radiator radiation commonly is made to care for secondary losses. The heat loss from the boiler and from the distributing mains, even when these are well-covered, may equal 25% of standing radiation; while, with boiler and pipes uncovered, it will amount to 50% or more, depending on the exposure of the boiler room and the exposure of spaces through which pipes are run.

Under (2) above, it was stated that radiators may be reduced by an amount equivalent to the area of piping serving them. In general, this is not considered good practice unless the amount of piping passing through the room in which the radiator is located is relatively large in proportion to the area of the radiator. When this is the case, considerable saving in cost of radiators may be effected by a careful consideration of this feature of the installation.

The surface of all mains and risers always should be considered with reference to the amount of steam they condense or their cooling effect upon the water.

In Table R-2-2 the lineal feet equivalent to 1 sq. ft. of external surface for different size pipe are given with which equivalent radiating surface easily may be computed by scaling the piping layout.

RADIATION OTHER THAN DIRECT

If radiation, other than the direct form is used, boiler capacity must be increased in proportion as those surfaces may condense steam or cool water

more or less rapidly than direct radiation. Such may be illustrated by considering the demands on a large steam boiler where excessive piping area makes the condition particularly impressive. The proportion of piping area to total radiating surface, however, may be little greater than found in many average installations.

Assume the total radiation area for a given installation to be 6000 sq. ft., representing that of all radiators and piping without respect to the kind of radiation.

Assume this total condensing or cooling area to be of three kinds, and distributed as follows:

	Sq. ft.
(A) Direct radiation standing in still air at 70° F.	= 3300
(B) Indirect radiation	= 1600
(C) Mains, branches, risers, and other piping standing in still air at 60° F.	= 1100
Total radiating surface	= 6000

Assume the rating of the boiler under consideration to have been made on the basis of 2 lbs. per square inch gage at the boiler and that every square foot of radiating surface standing in still air at 70° F. will condense ¼ lb. of steam per hour.

If the total surface of 6000 sq. ft. were all direct radiation standing in still air at 70° F., the boiler could be selected directly from a table of ratings prepared on the above stated basis. Such, however, is not proper since proper corrections and allowances must be made to care for differences in the condensing power of the various surfaces. Procedure is as follows:

First: Determine total steam required per hour for the direct radiating surface by dividing square feet of surface by 4 (1 lb. steam per 4 sq. ft.).

$$3300 \div 4 = 825 \text{ lbs. per hr.}$$

Second: Determine total condensation from the indirect radiation by dividing square feet of surface by its condensing rate. This rate depends upon the temperature and velocity of the air entering and passing through the indirect stack, its area, etc. For this example, assume 1 lb. per hr. for every 2.5 sq. ft. of indirect surface.

$$1600 \div 2.5 = 640 \text{ lbs. per hr.}$$

Third: Determine total condensation from the piping by dividing square feet of piping surface by its condensing rate. This rate will depend upon the temperature of the surrounding air and as to whether or not the pipe is covered; when covered, the material and thickness affect the rate of condensation. For this example, assume a rate of 1 lb. per hr. for every 3.33 sq. ft. of piping.

$$1100 \div 3.33 = 330 \text{ lbs. per hr.}$$

Fourth: Add results, First, Second, Third, and get the total required quantity of steam in lbs. per hr.

$$825 + 640 + 330 = 1795 \text{ lbs. per hr.}$$

Fifth: Express result Fourth in square feet of direct radiating surface by multiplying it by 4.

$$1795 \text{ lbs.} \times 4 = 7180 \text{ sq. ft. direct radiation.}$$

Sixth: Select a boiler rated to have ample capacity.

If the boiler selection had been made on the original figure of 6000 sq. ft. of radiating surface exposed to air at different degrees of temperature and air velocities, it would have been an improper selection. The above example shows that the increased steam condensing effects of the different radiating surfaces demands a boiler rated (as above) at not less than 7200 sq. ft.

Thus, by due consideration of the effect of *all* radiating surface, steam requirements are more definitely established and boiler selection is made on a more stable basis.

Work Problem B-3-6

TOTAL BOILER DEMANDS

It was explained in the foregoing that when selecting a boiler care should be taken to include *all* demands on the boiler. It also was stated that the condensing ability of the piping was governed by its covering or no covering. While it is not the purpose at this time to take up results of tests of different pipe coverings, the student should realize that the type of covering has much to do with heat loss from pipes.

Work Problem B-3-7

Heating boilers, especially for residence work or where attendance of the fire is not continuous, are rated to carry the square feet of direct radiating load for a definite period of time. A proper appreciation of the rating cannot be had unless there is stated the length of time that a boiler will carry its load on one supply of fuel.

An 8-hour firing period and an average condensing rate of 0.25 lbs. of steam per hour per square foot for radiators and piping is a common basis for tables of boiler ratings in terms of standard column direct steam radiation.

For water radiation, the steam rating may be multiplied by 1.6. In Lessons R-1 and R-2, the development of heat emissivity factors for different radiating surfaces and different heating media were explained. For average steam radiators, an emissivity of 240 B.T.U. per hr. per sq. ft. is commonly used; for water radiation, the factor is 150 B.T.U. per hour. So the ratio of 240 ÷ 150 or 1.6 represents the amount of net equivalent standard direct water radiation for a given amount of steam radiation.

If a given boiler has a rating of 500 sq. ft. for steam and 800 sq. ft. for water radiation, and the rating is made on the basis of an 8-hour firing period, a change in the ratings must be made should a different firing period be considered.

An understanding of the development of the 8-hour rating is essential. Tests must be run. All fuel used and steam produced must be carefully measured. With these data, the way is clear.

Assume a boiler fired with 161 lbs. of hard coal, 125 lbs. to be consumed during 8 hours with 36 lbs. as the reserve for rekindling and igniting the new charge. If during the 8-hour operating period it was found that 1000 lbs. of water had been changed into steam, then for every pound of coal burned during the 8 hours there was produced 1000 (lbs. water) ÷ 125 (lbs. coal) = 8 lbs. of steam.

This quantity, pounds of steam per pound of coal, is known as the evaporative power of the boiler.

Since 1 sq. ft. of radiation is considered to condense ¼ lb. of steam per hour, the rating of the

boiler on an 8-hour firing period may be found by dividing the total steam produced in that time by the product of the evaporative rate $\times$ ¼. Thus, for the example considered:

1000 (lbs.) $\div$ (8$\times$¼) = 500 sq. ft. (steam)
or 500 $\times$ 1.6 = 800 sq. ft. (water)

Work Problem B-3-8

If the firing period is 6 hours, the rating of the boiler may be referred to this basis by dividing the total steam produced during 8 hours by the product of 6 (hours) $\times$ ¼ (condensing rate). For the above case, the boiler on a 6-hour rating basis would be:

1000 (lbs.) $\div$ (6$\times$¼) = 667 sq. ft. (steam)
or 667 $\times$ 1.6 = 1067 sq. ft. (water)

Work Problem B-3-9

EFFECT OF INCREASED CONDENSATION RATE

The effect of condensation rate on capacity of the boiler was touched upon in connection with surface of piping, etc. It may be employed directly with the evaporating rate obtained from boiler test data.

The condensation rate of 0.25 lb. per hr. per sq. ft. of radiation will be greater in the case of an extended pin-type indirect radiator. For such a radiator having a capacity of 275 cu. ft. of air per hr. per sq. ft. of radiation, the condensing power of this radiator may be taken at 0.645 lbs. Therefore, if a boiler is to generate steam for such indirect radiators and its total evaporating power in an 8-hour test was 1800 lbs., its rating when supplying these radiators would be 1800 (lbs.) $\div$ (8$\times$0.645) = 349 sq. ft.

Work Problem B-3-10

CONDENSATION FACTOR

The coefficient of heat transmission for different types of radiators was given in Table R-2-1.

If the factor 1.65 is selected, as the number of B.T.U. given off per square foot of area in one hour per degree difference in temperature between that of the radiator and that of the surrounding air,

and this factor be multiplied by 150, the standard temperature range (the student is referred to Lesson 14 for a full discussion of the effect of temperature range on the transmission factor), the transmission rate for a steam radiator of 247.5 B.T.U. is obtained. (For rapid computations, the even number 248 is commonly used.)

Latent heat of vaporization was explained in Lesson 1 and in Lesson S-1. By Table S-1-1, the latent heat of evaporation is 970.4 B.T.U.

While the steam which condenses in a radiator is under a slight pressure with a consequent lower value for latent heat of vaporization, this value 970.4, so far as practical results are concerned, represents the number of heat units given up by each pound of steam condensed. Therefore, if 970.4 be divided by 248, the result, 3.91 shows the number of sq. ft. of radiation having a coefficient of heat transmissions of 1.65 that are required to condense 1 lb. of steam. Calling this 4 sq. ft., the condensation rate of 0.25 lb. per sq. ft. per hr. is obtained.

Work Problem B-3-11

If conditions are other than standard, then the radiator transmission factor must be determined as explained in Lesson R-2, and this value used to obtain the condensation rate factor.

When the number of gallons of water which must be heated in a given time is known, the rating of a hot water heater may be estimated as follows:

First: Determine and note the number of gallons of water to be heated. In the case of a hot water heating system, the total value of water in the system must be calculated and increased by as many times as complete circulation occurs per hour. (See Table R-1-8).

Second: Multiply result First by 8½ (lbs. per gal.) and obtain the total weight of water to be heated.

Third: Divide result Second by the number of hours in which the heating is to be accomplished and obtain the weight of water to be heated per hour.

Fourth: Subtract the initial temperature of the water from the final temperature and obtain the degree temperature rise.

Fifth: Multiply result Third by result Fourth and obtain total B.T.U. to be supplied per hour.

Sixth: Divide result Fifth by 150 and obtain a boiler rating for water heating in terms of sq. ft. of direct standing cast-iron radiation.

Work Problem B-3-12

CHECKING GRATE SURFACE

It is always advisable to check the suitability of a boiler by calculating the grate area required. If the heat loss from a building has been computed by the B.T.U. method, the heat to be supplied is known more accurately so that by checking the grate area, boiler selection is placed on a more firm basis.

The total heat loss must include, in addition to the calculated losses, the heat given off from the piping system and boiler.

Required grate area may be determined as follows:

First: Multiply B.T.U. loss from the building by 1.25 or 1.50 depending on relative proportion of piping to radiator area and get the total heat requirement.

Second: Assume a rate of combustion suited to conditions. See Table B-1-1.

Third: Select a heat value for the fuel as B.T.U. per 1 lb.

Fourth: Assume a value for combined efficiency of boiler and grate.

Fifth: Obtain product of results Second $\times$ Third $\times$ Fourth.

Sixth: Divide result First by result Fifth and obtain the area of grate in square feet required for the existing conditions.

Work Problems B-3-13, B-3-14

EFFECT OF FUELS ON RATINGS

Since the majority of the tables for boiler ratings found in the various catalogs of manufacturers are based on the use of anthracite coal, of

stove size, the effect of using other size or kind of coal must be taken into consideration where anthracite is not to be used or where it may be desirable to change the kind and grade of fuel.

Bituminous coal occupies about 25% more space than the same weight of anthracite which, if used, demands the selection of a boiler having at least 25% greater capacity. Also, if soft coal is to be used, additional boiler heating surface is required, since the accumulation of soot from such coal renders the heating surface less effective than when hard coal is used.

Since the smaller sizes of anthracite are likely to contain more ash than the larger sizes, and hence have a greater bulk for the same heating effect, the use of pea, buckwheat and chestnut sizes may make it advisable to provide a larger fuel pot. See Lesson B-1, for determining sizes of fuel pot.

DOMESTIC HOT-WATER REQUIREMENTS

Hot water requirements differ for almost every residence. The number of persons, their habits, etc., determine the total hot water demand. No hard and fast rule can be stated by which exact demands can be foretold. The heating unit, however, should be capable of heating ample water to meet peak conditions. Generally speaking, an allowance of 7 gal. per person per hour with a reserve of approximately 50%, is a safe figure. If washing machines and extra lavatories are installed, a greater amount can safely be allowed. Tank capacities should be the nearest standard above the 150% estimated.

Accurate rules for determining increased demands on the boiler are difficult to express since there are so many variable factors to consider.

Some estimate, nevertheless, always should be made, and the effect of this additional demand for heat upon boiler capacity required should be considered when making the selection.

When a pipe coil is in contact with a good fire, there may be expected a heat transmission of about 15,000 B.T.U. per sq. ft. per hr.

TABLE B-3-1. HOT WATER REQUIREMENTS (APPROXIMATE)

No. Persons	Gal. Water per Hour (Max.)	Tank Capacity (Gal.)
2	14	30
3	21	32
4	28	40
5	35	52
6	42	66
7	49	82
8	56	82
9	63	100
10	70	100

On this basis, if water be raised in temperature from 50° to 150° F. or through 100° F., every square foot of coil will heat about 18 gal. of water per hour. Common practice allows 15 gal. per sq. ft. of submerged coil.

When the coil is placed above the fire, the heat transmission materially is reduced, depending upon the intensity of the fire.

LENGTH OF COILS REQUIRED

The length of coil required for a given installation frequently is needed. Table B-3-2 contains lengths expressed in feet for four different sizes of pipe.

Calculations on the basis of 10 gal. per hr. are as follows:

Transmission rate (coils in contact with fire) = 15,000 B.T.U. per hr.

Water heated from 50° to 150° F.

Weight of water heated = 10 (gal.) $\times$ 8.3 (lbs.) = 83.33 lb.

B.T.U. required = 83.33 (lb.) $\times$ 100 (tem. diff.) = 8333 B.T.U. per hr.

$$\text{Sq. ft. of surface required} = \frac{8333}{15{,}000} = 0.55 \text{ sq. ft.}$$

Lineal feet of 1-in. pipe = 0.55 $\div$ 0.344 = 1.45 ft.
1¼-in. pipe = 0.55 $\div$ 0.435 = 1.15 ft.
1½-in. pipe = 0.55 $\div$ 0.498 = 1.00 ft.
2-in. pipe = 0.55 $\div$ 0.622 = 0.80 ft.

Reduction of 25% to allow for ashes, etc.
To heat 10 gal. of water per hour requires

1.10 ft. of 1-in. pipe.
0.86 ft. of 1¼-in. pipe.
0.75 ft. of 1½-in. pipe.
0.60 ft. of 2-in. pipe.

TABLE B-3-2. LENGTHS OF COILS REQUIRED IN FIRE BOX FOR HEATING DOMESTIC WATER SUPPLY

Water Heated, Gal. per Hour	Nominal Pipe Size			
	1 In.	1¼ In.	1½ In.	2 In.
	Length of Pipe in Feet			
10	1.10	0.86	0.75	0.60
15	1.65	1.29	1.12	0.90
20	2.20	1.72	1.50	1.20
25	2.75	2.15	1.88	1.50
30	3.30	2.58	2.25	1.80
35	3.85	3.00	2.62	2.10
40	4.40	3.45	3.00	2.40
45	4.95	3.86	3.36	2.70
50	5.50	4.30	3.75	3.00

If the pipe coil is above the fire and therefore not in direct contact therewith, the heat transmission materially will be less. Thus, for domestic installations, the above lengths properly may be increased 50% for the respective capacities.

PART B.

STEAM AND WATER BOILERS

LESSON 4.

Tests and Efficiencies

BOILERS.

Efficiency is a term often loosely used in connection with boiler operation. A boiler may be highly efficient, but the term is meaningless without a definition of the conditions under which the efficiency was determined. The efficiency of a boiler is not that of a heating system in which it may be used; a boiler of high efficiency may be incorporated in a heating plant that, due to no fault of the boiler, may be very inefficient.

The student should appreciate fully that boiler efficiency and the efficiency of a heating system are two totally different things. True, an efficient boiler contributes its share toward an efficient heating system, yet the most efficient boiler, in itself, cannot assure a high over-all efficiency of the entire heating plant.

BOILER EFFICIENCY

If there is burned, in a boiler, in one hour, 20 lbs. of a certain coal, containing 12,500 B.T.U. per pound, the total heat energy made available is $20 \times 12{,}500 = 250{,}000$ B.T.U.

If a test made, while burning this coal at a uniform rate, shows that, during the hour, there has been delivered to the water in the boiler 140,000 B.T.U., then $140{,}000 \div 250{,}000 = 0.58$, which is the decimal part of unity representing the output of the boiler divided by its input; it is the ratio of energy utilized to energy expended. Multiplying this decimal by 100 converts the ratio to percentage, and the efficiency of the boiler, as shown by the test just cited, would be 58%.

Such a figure can be obtained for any boiler, when arrangements are made to secure the necessary readings, and when the conditions under which the boiler operates can be controlled and maintained constant.

To say that a boiler will operate at a stated efficiency as part of a heating system is to assume that all conditions, at all times, under such operation, are identical with those occurring under the test conditions when the stated value for efficiency was established.

Too much emphasis, therefore, cannot be laid upon the fact that the efficiency of a boiler can be stated only *for a definite load and under specific conditions of operation.* A boiler operating under a fluctuating load would have a corresponding fluctuating efficiency, and variations other than the load, such as changes in climatic conditions, change in feed-water temperature, and so on, would again change the output-input ratio.

Boiler efficiency, therefore, should not be regarded as a fixed quantity, for, indeed, it is different with varying conditions. It is practically impossible to say that a draft of a certain intensity will be developed in a certain chimney. And variations in draft are important in influencing boiler efficiency. To say that a boiler of certain make, or design, will develop an efficiency of 50%, 60%, 70% or 80% is to give the impression that boiler

efficiency is an inherent part of the boiler, when, as explained, operating conditions, in large measure, control boiler efficiency.

Every boiler has an "efficiency curve." To obtain this curve for a given boiler, it is necessary to make a series of tests at different rates of combustion. During such tests many data are taken, from which may be calculated the quantities and rates of energy utilized and wasted.

HEAT LOSSES

The losses of heat which occur during a boiler test (and when the boiler is in operation, in service) may be enumerated as follows:

(1) Losses up the chimney.
(2) Loss through the grate, if coal is the fuel.
(3) Loss due to radiation of heat from the boiler shell.
(4) Loss due to combustion of only part of the fuel.
(5) Loss due to moisture in the air used for combustion.
(6) Loss due to convection currents, and unaccounted losses.

Since losses (3) to (6), inclusive, are relatively small, especially those designated as (4) to (6), inclusive, these last four frequently are included under one heading and are listed as "radiation and other losses."

Heat lost up the chimney represents, by far, the greatest part of the heat that is not usefully employed. The products of combustion pass up the chimney. In order that there may be a movement of air through the boiler and chimney it is necessary that the temperature of air or gases in the boiler and stack is higher than the temperature of the outside air surrounding the chimney. Thus, since draft action is necessary for the operation of a boiler, a portion of the heat escaping through the chimney really does useful work, and is not an unnecessary loss. The total heat carried up the chimney usually is much greater than is necessary for draft purposes, and represents an operating loss.

Chimney losses are of two kinds, (a) unconsumed combustible in the fuel, such as soot and gases which are not completely oxidized which, if completely burned, would give off additional heat, and (b) excess heat actually wasted in the chimney gases.

Under certain conditions the soot and unburned gas loss may be high. If too much air is fed to the fire it may reduce the temperature in portions of the combustion chamber to less than the ignition temperature of some of the combustibles and thereby prevent complete combustion. If too little air is admitted, there will not be enough oxygen to permit complete combustion of the fuel. Thin fires (in the case of coal), holes through the fire bed, open fire-doors and open joints frequently result in too much air being admitted. Firing too much coal at one time increases the resistance through the fire and decreases the air flow.

GRATE AND ASH-PIT LOSSES

Grate and ash-pit losses, naturally, apply to coal-burning plants and are largely due to excessive and too-frequent shaking. Whenever unburned or partially-burned coal passes through the grates with the ashes, this loss occurs. Improper size openings in or between the grate bars, for the size or kind of coal used, may cause this loss to be abnormally high.

RADIATION AND OTHER LOSSES

While heat radiated from an uninsulated boiler may be considered as useful in heating the basement, and thus assist in providing a warmer floor above, it must be considered as a loss when computing boiler efficiency, as it is not delivered at the boiler outlet for controlled distribution. As a practical matter boilers usually are lagged with an insulated cover; much depends upon the location of the boiler and the possibility of utilizing this radiated heat. Always, in computing boiler efficiency, radiation and convection losses are real and included in the "loss" column.

Other losses usually "lumped" with the radiation loss are the heat required to evaporate any moisture that may be present in the air used for combustion and the latent heat of the water formed from combustion of the hydrogen in the fuel.

When boiler tests are conducted, provision is made for taking the necessary readings from which may be determined how all the heat in the fuel is expended. From these readings, and knowing the analysis of the fuel, a heat balance may be prepared.

DATA REQUIRED FOR PREPARING HEAT BALANCE

	TEMPERATURES	
t_a	AIR TEMPERATURE, DRY BULB	70°F.
	WET BULB	65°F.
t_f	TEMPERATURE OF FUEL AS FIRED	70°F.
T	TEMPERATURE OF FLUE GASES	645°F.
	ULTIMATE ANALYSIS	
C	CARBON, PER CENT	79.50
H_2	HYDROGEN, PER CENT	2.43
O_2	OXYGEN, PER CENT	1.68
N_2	NITROGEN, PER CENT	0.75
S	SULPHUR, PER CENT	0.81
	MOISTURE IN FUEL, PER CENT	1.44
M	, LB. PER LB. FUEL	0.0144
	ASH, PER CENT	13.39
	FLUE GAS ANALYSIS	
CO_2	CARBON DIOXIDE, PER CENT	17.2
O_2	OXYGEN, PER CENT	2.3
CO	CARBON MONOXIDE, PER CENT	0.0
N_2	NITROGEN, PER CENT, BY DIFFERENCE	80.5
	BY ANALYSIS	
S	ASH AND REFUSE, PER CENT DRY COAL	6.97
S	UNCONSUMED CARBON IN ASH, PER CENT	27.54
	HEAT VALUE OF FUEL	
H	B.T.U. PER LB DRY COAL	12790

Fig. B-4-1. Fundamental Information Necessary for Computing Heat Balance

HEAT BALANCES

A heat balance may be prepared on the basis of 1 lb. of fuel. The quantities are expressed in one or both of two ways.

(a) Heat balance, per pound fuel as fired.

(b) Heat balance, per cent heat in fuel as fired.

Previous to the preparation of a heat balance, three things must be done:

(1) An ultimate analysis of the fuel is made and its heat value in B.T.U. per pound determined.

(2) A test is conducted with the boiler, using the particular fuel.

(3) Computations of all losses are made and a distribution of the heat evolved from the combustion of the fuel is determined.

An example showing the data required, as ob-

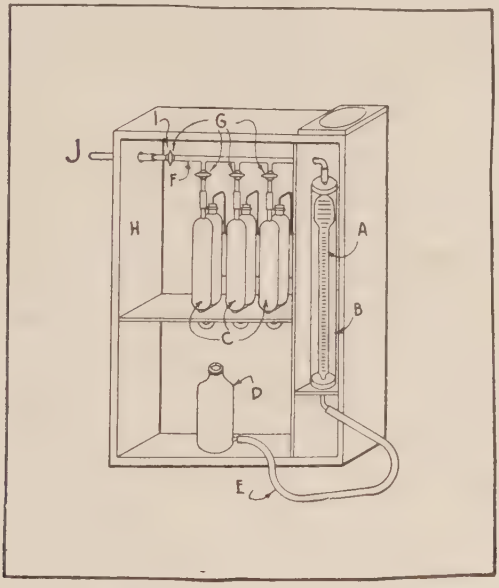


Fig. B-4-2. Orsat Apparatus

tained from a test of a coal-burning boiler, is shown in Fig. B-4-1.

Temperatures are obtained with suitable thermometers. The ultimate analysis of the fuel must be made in a laboratory equipped for such work. Fuel samples are taken in a duly prescribed manner during the test, sealed and forwarded to the laboratory.

The flue gases are analyzed from samples taken from the smoke pipe just after the gases have

passed the last heat-absorbing part of the boiler. Such samples often are gathered at stated intervals during the test and analyzed at once. A sample taken in this way is called a "grab" sample, requires but a few seconds to secure, and serves to indicate conditions at the time and place where the sample is collected. When conditions justify, it is better to use continuously selected samples which are collected during several hours. Naturally, such are more representative than those "grabbed" and often are to be preferred when the composition of the gases determined therefrom are to be used as the basis for a report on operation. The average values from a number of samples taken and analyzed at frequent intervals during the test, however, usually may be taken as indicative of conditions.

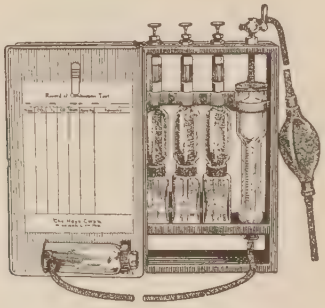


Fig. B-4-3. Portable Type Orsat Apparatus

(Courtesy the Hays Corp.)

HEAT BALANCE

PER LB. FUEL AS FIRED

SYMBOL	QUANTITIES	B.T.U.	PERCENT
L_1	LOSS DUE TO MOISTURE IN THE FUEL	19	0.1
L_2	LOSS DUE TO BURNING HYDROGEN OF THE FUEL	287	2.2
L_3	LOSS DUE TO MOISTURE IN AIR USED FOR COMBUSTION	36	0.3
L_4	LOSS IN DRY CHIMNEY GASES	1532	12.0
L_5	LOSS DUE TO UNCONSUMED COMBUSTIBLE IN ASH AND REFUSE	280	2.2
L_6	LOSS DUE TO UNCONSUMED GASEOUS COMBUSTIBLE MATTER	0	0.0
L_7	LOSS DUE TO RADIATION FROM HEATER	3069	24.0
L_8	LOSS DUE TO CONVECTION AND UNACCOUNTED FOR LOSSES		
	USEFULLY APPLIED HEAT	7567	59.2
	B.T.U. PER LB. OF FUEL	12790	100.0

Table B-4-1

Analysis of flue gases is made with an Orsat apparatus. A typical instrument is illustrated in

Fig. B-4-2 while a portable type with half-size burette is shown as Fig. B-4-3.

The instrument consists essentially of a measuring burette A, a water-jacket glass cylinder B, three absorption pipettes, C, a leveling bottle D, connecting rubber tubing E, a glass header F, ground-glass stop cocks G, and a case H for enclos-

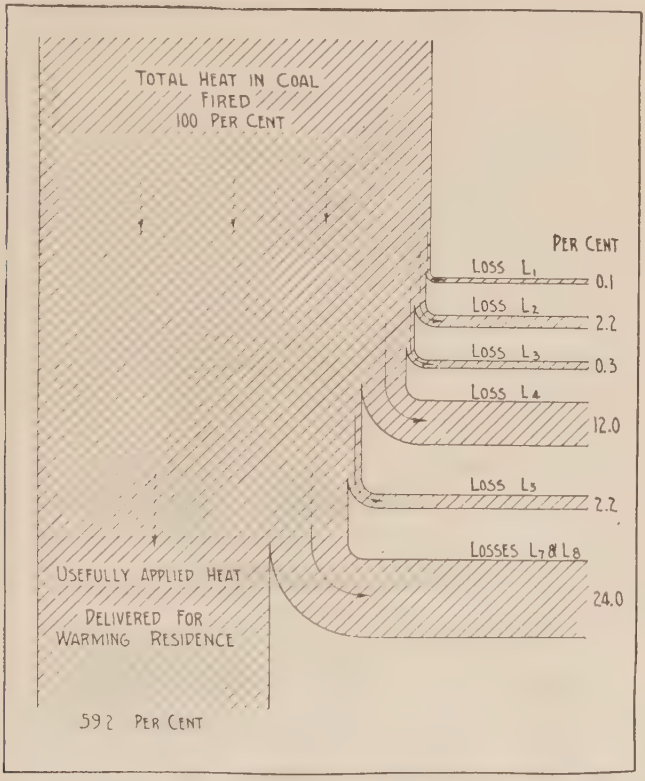


Fig. B-4-4. Graphic Representation of Heat Distribution

ing the apparatus. The stop cock marked I is a 3-way stop cock so that gas may pass into the header from tube J or may be discharged to the atmosphere from the header through an opening (not shown) on the rear side.

The measuring burette A is of cylindrical glass, graduated in 100 units, with each unit divided into five parts. Orsat apparatus are built full and half size. The burette of a full-size Orsat has a volume of 100 cubic centimeters (100 c.c.) while the volume of the half-size burette is 50 c.c.

HEAT BALANCES

DATA FROM TESTS USING ANTHRACITE COAL

SYMBOL	QUANTITIES	B.T.U. PER POUND OF FUEL AS FIRED			PER CENT HEAT IN FUEL AS FIRED		
		A	B	C	A	B	C
L_1	LOSS DUE TO MOISTURE IN THE FUEL	38	36	33	0.3	0.3	0.3
L_2	LOSS DUE TO BURNING HYDROGEN OF THE FUEL	354	340	312	2.8	2.6	2.4
L_3	LOSS DUE TO MOISTURE IN AIR USED FOR COMBUSTION	53	20	22	0.4	0.2	0.2
L_4	LOSS IN DRY CHIMNEY GASES	2543	2025	1106	19.8	15.7	8.6
L_5	LOSS DUE TO UNCONSUMED COMBUSTIBLE IN ASH AND REFUSE	633	200	345	4.9	1.6	2.7
L_6	LOSS DUE TO UNCONSUMED GASEOUS COMBUSTIBLE MATTER	238	0	0	1.8	0.0	0.0
L_7	LOSS DUE TO RADIATION FROM HEATER	326	310	419	2.5	2.4	3.3
L_8	LOSS DUE TO CONVECTION AND UNACCOUNTED FOR LOSSES	2437	3167	492	19.0	22.2	3.7
	USEFULLY APPLIED HEAT	6248	7082	10141	48.5	55.0	78.8
	B.T.U. PER LB. OF FUEL	12870	12870	12870	100.0	100.0	100.0

Table B-4-2

The water-jacketing cylinder B is rubber stoppered at the top and bottom and completely encloses the burette A in a water bath so as to maintain the gas at practically a constant temperature during analysis.

The absorption pipettes C are U-shaped glass vessels about 1¼ in. in diameter with the connecting U at the bottom of about ⅜-in. glass tubing. The front arm of the pipette is filled with nested glass tubes with top and bottom open so as to increase the interior glass surface. The other arm of the pipette is connected to a water seal or rubber bag (Fig. B-4-2 shows rubber-bag connection) which forms an air seal for the solution in the pipette. Each of the pipettes contains a different solution. That nearest the burette contains potassium hydroxide solution used for absorbing carbon dioxide; the second pipette contains an alkaline solution of pyrogallic acid used for absorbing oxygen, and the third pipette contains an ammoniacal solution of cuprous chloride used for absorbing carbon monoxide.

The Orsat apparatus is becoming more appreciated every day, not only for boiler test work, but for checking up on boiler operation either with coal or oil. The analysis of the flue gases tells the true story of the quality of combustion. It is not the province of this course to go into a discussion of combustion which is to be thoroughly covered in a subsequent course. The student, however, should appreciate (a) that efficient combustion is essential for efficient boiler operation (b) that combustion efficiency should not be confused with boiler efficiency and (c) that it is perfectly possible to have a boiler show high combustion efficiency and relatively low overall efficiency.

Referring again to Fig. B-4-1, the remaining three quantities, those by analysis and the heat value of the fuel must be obtained from laboratory analysis. Samples of the ash removed from the ash pit of coal burning plants are collected in a proper manner and sealed immediately. The heat value of the fuel is determined by means of an instrument known as a calorimeter.

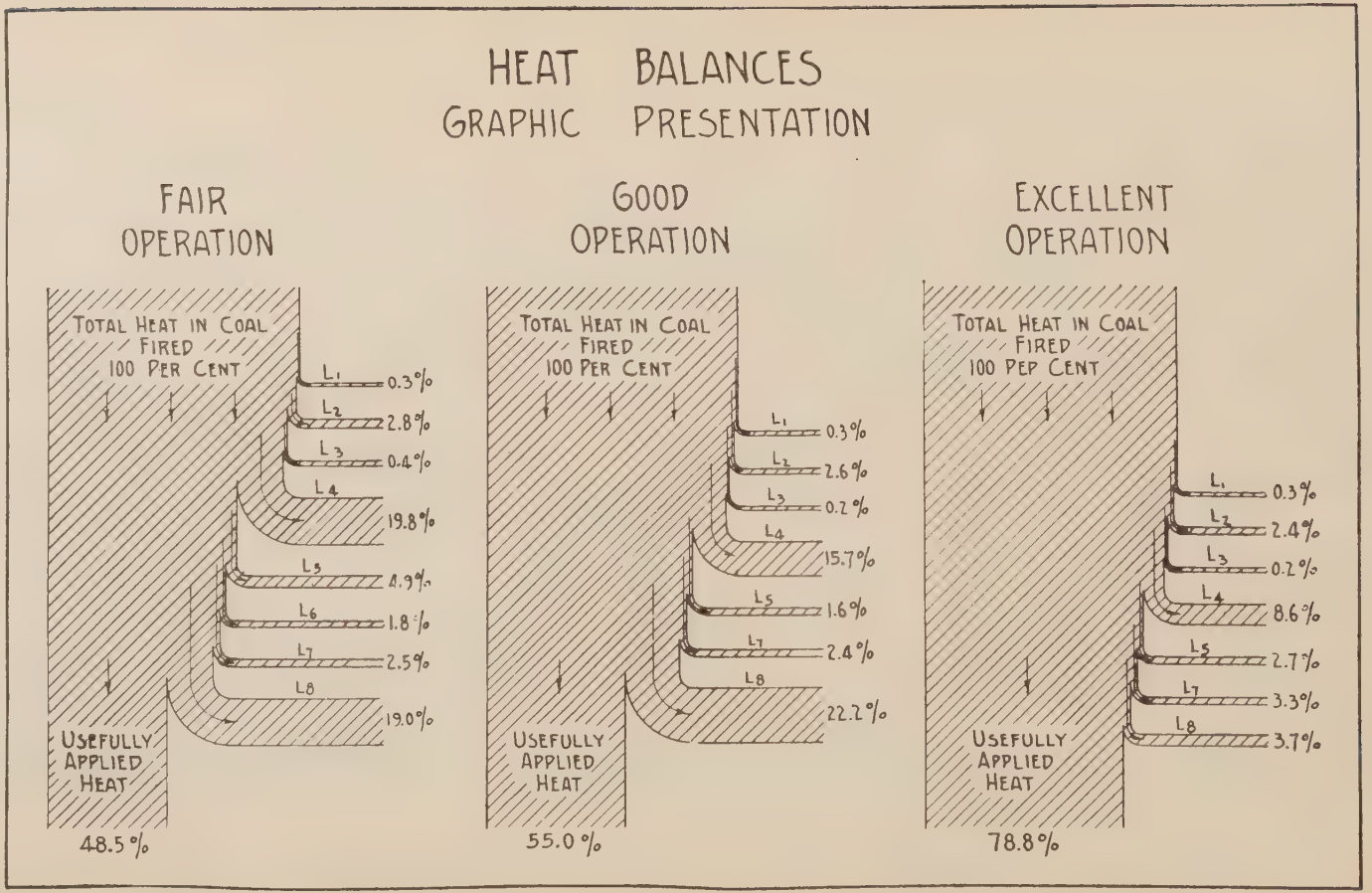


Fig. B-4-5. What Happens to the Heat Resulting from Coal Combustion in a Boiler Furnace Under Different Conditions of Operation

On the basis of the ultimate analysis, heat value of the fuel used and test data gathered as given in Fig. B-4-1, there is illustrated graphically, in Fig. B-4-4, the heat available in the anthracite coal as fired and the distribution of this heat as determined by the test of the plant using it.

The total heat in the coal is plotted as 100% represented by the width of the chart at the top. The usefully applied heat delivered for warming the residence is shown as 59.2% and is represented by the width of the chart at the bottom. The quantities chargeable to the different losses are shown on the right of the chart. Each loss is designated by the letter L with a sub-number. They are enumerated in Table B-4-1.

The data shown in Table B-4-1 are the result of one test. As stated in the foregoing, boiler efficiency will differ with change in the combustion rate; distribution of losses changes and so it is necessary to treat each test separately.

Table B-4-2 shows three heat balances for the same boiler when operated with the same fuel but at different rates of combustion. A graphic presentation of these three heat balances is shown in Fig. B-4-5 where plant operation is noted as fair, good and excellent.

After a sufficient number of tests has been conducted, a boiler-efficiency curve, together with other characteristic curves, may be prepared.

Such a set of curves is shown as Fig. B-4-6. Combustion rate, in pounds of coal per square foot of grate per hour, has been taken as the basis of comparison. The boiler to which these curves apply was operated at rates from about 4.95 lbs. to 12.4 lbs. of coal per square foot of grate per hour.

The boiler-efficiency curve is typical of cast-iron, low-pressure heating boilers. Practically, they all have a "hump" indicating the point of highest efficiency which generally corresponds to a rate of fuel consumption between 5 and 7 lbs. per square foot of grate per hour. For the curve shown, it is apparent that an efficiency of slightly over 70% was obtained at a 6-lb. rate. When the boiler was forced by increasing the rate to 12 lbs. the efficiency fell to 61%. Thus it is apparent that a

boiler showing highest efficiency at a 6 lb. rate should, if possible, be fired during the greater part of its operating period at or near this rate.

The heating-effect curve is plotted as total heat in B.T.U. added to the water per hour. At the lower combustion rates, this curve has a steep appearance, while at the higher rates, it begins to flatten, indicating that, although the fuel rate is increased, heating effect does not follow in the same ratio.

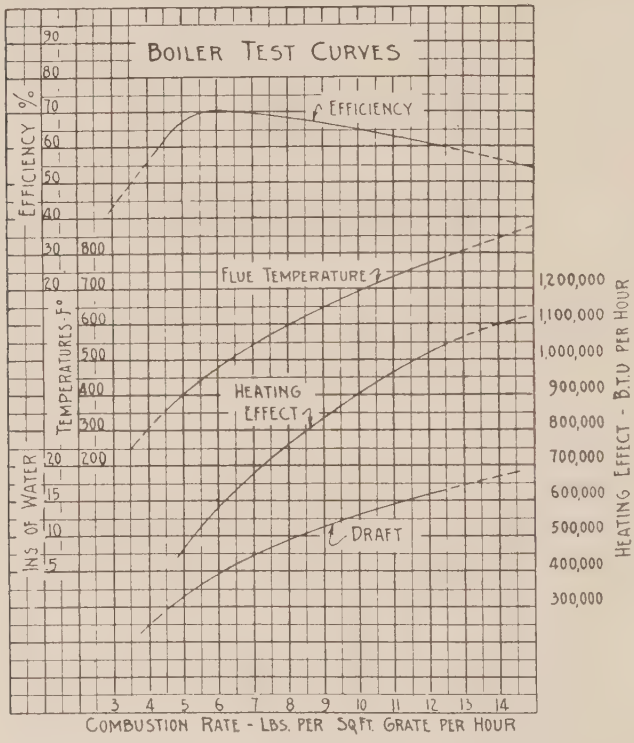


Fig. B-4-6. A Typical Set of Boiler-Test Curves

The draft curve shows the rate at which draft increases as more fuel is burned.

It should be noted that the flue-gas temperature curve rises fairly rapidly so that for the higher rates of combustion, the high flue-temperatures largely are responsible for the lower efficiency.

A study of similar curves from several boilers materially will aid the student in forming a true appreciation of boiler operation.

PART B.

STEAM AND WATER BOILERS

LESSON 5.

Installation Details

BOILERS.

Connections for steam and water heating boilers require consideration from the viewpoints of (a) expansion of the piping, (b) number and size of outlets, (c) local conditions governing arrangement of piping.

There are required (a) steam or supply connections from the top, (b) water or return connections at the bottom, (c) top and bottom blow-off connections, (d) a drain line and (e) a cold-water filling line.

Fig. B-5-1 shows approved methods for making connections to a single boiler, while Fig. B-5-2 shows two boilers cross-connected, using check valves and so valved otherwise that either boiler may be used independently or both may be in service at the same time. Piping methods for cross-connecting boilers are many and varied. Equalizing pipes on both supply and return sides, as shown

in Fig. B-5-2, are not always installed. Their use is advisable.

For steam work, angle or globe valves are used on the supply connections, and gate valves for the return lines for cross-connecting piping. For water boilers, gate valves should be used on both sides.

Contrary to the practice of many, boiler outlets and inlets should not be bushed but connected full size. The number and sizes of supply openings determine the outlet velocity, while the number and sizes of inlet openings have been established to assure uniform distribution of the return water over the boiler heating-surfaces.

Steam heating-boilers, unlike power boilers, are not provided with means for assuring dry steam entering the supply lines through the use of "dry pipes" or "separators." Hence, velocity of flow through the outlets of such boilers should be relatively low—not over 15 ft. per second, if the carrying over of water with the steam is to be avoided. Drip connections for the header, therefore, are an essential. These considerations should be borne in mind when boiler connections are being designed or installed.

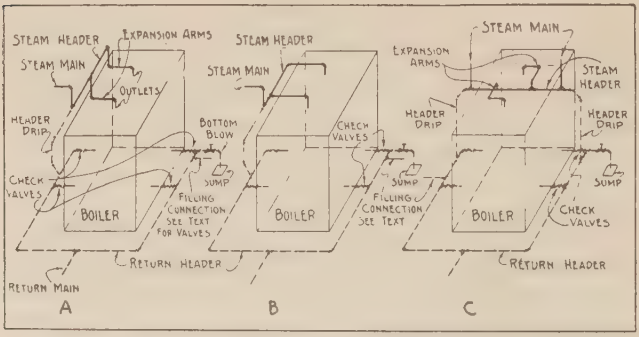


Fig. B-5-1. Typical Heating-Boiler Connections for Single Boiler

The filling connection for steam boilers on the better class of work should be fitted with two standard gate valves and with a swing check valve placed in a horizontal run of piping. The use of a check guards against the danger of an excessive boiler pressure backing up into the plumbing system.

In cross-connecting two steam boilers of unequal size or height, care must be observed to place them in such positions that the normal water-line level of one is the same as that of the other. A pit may be required for the larger or a foundation for the smaller.

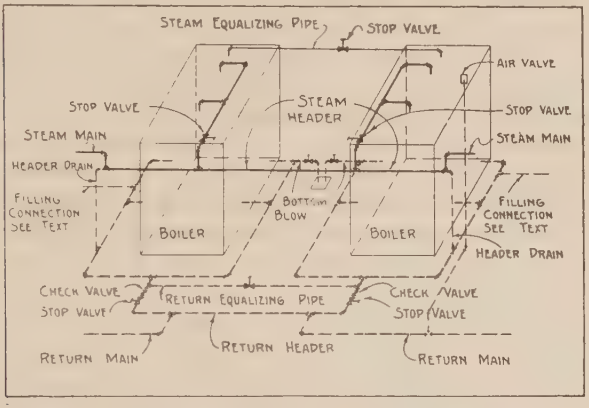


Fig. B-5-2. Typical Piping for Cross-Connecting Heating Boilers Using Check Valves and Equalizers in the Returns

Fig. B-5-3 illustrates the Hartford loop as applied to one or a battery of boilers. This method of boiler connection originally was designed by the Hartford Insurance Company and it eliminates the use of check valves.

The size of the equalizing pipe depends upon the grate area according to the following table.

Table B-5-1.
Equalizing Pipe Sizes
for
Hartford Loop.

Grate Area Sq. ft.	Pipe Size In. Diam.
Under 4	1½
4 to 15	2½
Over 15	4

This equalizing pipe may be connected to the header, to the supply main, or to a supply tapping at the top of the boiler and to a return tapping at the bottom. The return mains should be connected into the equalizer pipe 2 in. below the boiler water-line.

This system, in addition to eliminating check valves from the return mains, assures a steadier

water-line and prevents water being drawn from the boiler through formation of a partial vacuum, due to the cooling of the system.

CLEANING

Uncleaned boilers may be the cause of seemingly faulty heating systems. No installation job is complete or finished until the boiler has been thoroughly cleaned.

Boilers were used to generate steam for power long before their use for heating. Hence, the heating boiler is a form of the power boiler. Not always, in this adaptation, has proper consideration been given to the two distinct classes of service.

Sediment in power boilers causes sluggish circulation and retards heat transmission from fire to water with resulting reduction in power. Oil or grease in heating boilers causes priming and unsteady water-line, which, while these affect output, may be manifested somewhere else about the system and thus divert suspicion from the possible condition of the boiler.

In order to transmit heat throughout the piping and radiators of a steam heating-system uniformly, effectively and economically, the steam should be dry. Dry steam will circulate more rapidly and effectively than heavier wet steam. Wet steam flows slower, may be sluggish, tends to "fill" pipes with water at the turns, causes pressure-loss with resulting increased condensation, which, accumulating in drops from the mains, can interfere in the operation of air-relief equipment. With oil or grease on the water surface of a boiler, dry steam cannot be generated.

Power boilers were and are provided with a mud blow-off located near the bottom for clearing sediment and scale deposits. Heating boilers cannot be cleaned properly of oil and grease by bottom blowing. The job must be handled from the top as well. Plugs sometimes are provided on the side of the steam dome for surface blowing which, obviously, are to be used for cleaning purposes. Such, however, are not a part of all heating boilers, especially those of the small and moderate-sized residence type.

Oil, grease and grit from the piping and radiation of a heating system, slowly, are washed down into the boiler. The presence of such often may be apparent when the boiler is first put in service; or, it may require from one week to a month or longer for this foreign matter to find its way into the boiler. Where the piping system has drops fitted with plugs so as to permit blowing out grease and dirt that may have accumulated in the drops, this should be done before cleaning of the boiler is begun, and then repeated after the cleaning process.

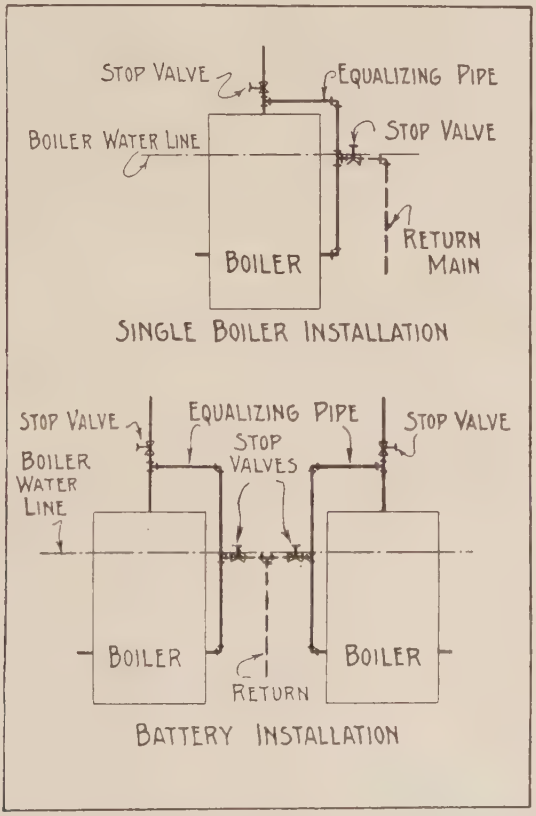


Fig. B-5-3. Application of the Hartford Return-Loop for Installations of Single Boilers and Batteries of Boilers

The operations in cleaning a steam boiler as recommended by many boiler manufacturers are enumerated as follows:

First: Draw fire in boiler and drain water from the entire system.

Second: Close all radiator valves.

Third: Close valves on supply and return main (if such are installed).

Fourth: Remove damper regulator and plug opening.

Fifth: Remove the safety valve and connect a blow-off pipe to the opening and extend this pipe to a suitable drain outside the building. The size of this pipe should be not less than the size of the safety valve and should be provided with a full-size cock or gate valve.

Sixth: Fill boiler with water to the proper level and with valve closed in safety-valve line build and develop a hot fire creating a steam pressure between 5 and 10 lbs. per square inch. Do not exceed 12 lbs. pressure.

Seventh: With pressure of 5 to 10 lbs. on the boiler, open valve in safety-valve line and permit the passage of water, steam, oil and grease to pass to the drain. Continue this operation for at least 2 hrs. and possibly for 6 to 8 hrs., depending on the condition of the water driven off, maintaining continuously a pressure of about 10 lbs. per square inch. During this operation feed cold water into the boiler at the bottom so as to maintain the boiler water-line at the top of the gauge glass.

Eighth: During the last hour or two, depending on time devoted to boiling out process, fill the boiler full of water and allow the water to flow through and out the safety valve blow-off line.

Ninth: Close the water-feed valve and permit water and steam to flow through the safety-valve line until the water level in the boiler is at the top of the gauge glass. The steam gauge should indicate at least 10 lbs. pressure when this level is established.

Tenth: Close the gate valve in the safety-valve line and immediately open the bottom blow-off valve, drawing the fire enough to avoid building up excessive pressure.

Eleventh: Drain boiler completely, maintaining just sufficient fire to the end to assure a pressure for driving out the last gallon of water.

Twelfth: Pull remaining fire immediately, open all fire and flue doors so as to cool off the boiler;

close bottom blow-off valve, remove safety-valve pipe line, replace safety valve and damper regulator (if installed) and fill boiler to normal water-line.

Thirteenth: Open main- and return-line valves and all valves on radiators, and build new fire.

Fourteenth: Steam the boiler to a pressure of about 5 lbs. and test for cleanliness:

(a) by opening gauge cock so as to emit steam or vapor and observe whether it is invisible as it jumps from cock and leaves a short gap between end of cock and steam; it should not condense readily or form bubbles on the inside of the glass.

(b) or by drawing a sample of water to a depth of 2 in. or 3 in. from the gauge cock into a vessel at least 3 in. in diameter and 8 to 12 in. deep, and boiling the sample over a hot fire and observing whether the boiling causes it to foam and overflow the vessel. If the water is clear and free from oil, grease, or impurities, no foaming will be evident, and bubbles from the boiling water will be seen plainly at the top.

CLEANING THE GAUGE GLASS

The gauge glass should be kept clean so that it will indicate clearly the true water level in the boiler. Oil and grease will dirty the glass and it may be advisable to clean it before waiting until the boiler is drained. The steam pressure on the boiler before commencing this cleaning should be at least 1 lb. The approved method of cleaning is as follows:

First: Draw about a pint of water from the pet cock at bottom of gauge and into this put a tablespoon full of hydrochloric acid.

Second: Close all gauge cocks.

Third: Open top gauge cock and pet cock at bottom and blow water out of the glass.

Fourth: Quickly close the top cock and submerge the bottom pet cock in the water-acid solution so that the vacuum action will fill the gauge glass with water-acid solution.

Fifth: With the bottom pet cock completely immersed, alternately open and close the top gauge cock so as to expel and refill the gauge glass with

the water-acid solution until all grease, oil or other matter on the inside of the glass is removed.

Sixth: Close bottom pet cock and open both water-gauge cocks.

GENERAL CHARACTERISTICS OF BOILER SELECTION

The selection of a boiler seldom has consideration commensurate with the importance which rightly belongs to it. Unfortunately and too frequently, boiler selection is the result alone of reference to catalogs and requests for proposals. The heart of the heating system is considered by many to be any cast-iron or steel boiler fitted with a grate for coal burning, having an ash-pit and capable of holding water, with a figure opposite its designation in a catalog that is somewhat greater than the total standing direct radiation on the job with which it is to be used.

Water may be heated or boiled and steam may be generated with almost anything called a boiler. But to make steam with consumption of least fuel and least attention, careful, proper and thoughtful consideration should precede boiler selection. Without performance data, boiler selection is like groping in the dark. Without due consideration of the relation of operating demands to boiler efficiencies, boiler selection is little more than guesswork. A boiler that is too small must work near its highest per cent of maximum output, which may mean relatively low efficiency. If too large, it operates much of the time at such a low per cent of its output that its efficiency is also relatively low. In both cases, too much fuel is burned.

Performance tests of boilers usually will indicate somewhat higher efficiencies for steel than for cast-iron types, especially in the larger sizes. Steel boilers cost more than cast-iron boilers. A steel boiler generally is received as a complete unit requiring only that it be placed in its proper position. Cast-iron boilers are designed generally to permit their handling through standard sizes of doors or windows. Skill is required in assembling or "setting-up" cast-iron boilers. If a steel boiler is to be used, it is necessary to know that it can be taken into the building through existing open-

ings. All these and other considerations must be borne in mind when deciding between a cast-iron or steel boiler.

PROVISIONS FOR EXTENSION

Oftentimes, it becomes necessary to extend the heating system by the addition of radiating surface, or a more elaborate piping layout to care for an adjoining structure. Such possibility should be considered when originally designing the system and selecting the boiler. Cast-iron boilers (sectional or round) may have capacities increased to certain limits by the addition of sections. Increased capacity for a steel boiler usually means replacement by a boiler of larger capacity or by the installation of a second boiler.

CONSTRUCTION FEATURES

The construction features have much to do with successful boiler operation and are points that very properly should enter into selection. For instance, with shaker bars extending through large holes in the base, with ash-pit and fire doors loose fitting, control of the fire is almost impossible, so that the heating plant is a nuisance rather than a convenience. Where low basements demand boilers with low water-lines, it is essential to avoid a boiler in which combustion space and heating surface have been sacrificed to obtain a low water-line. All draft doors and check dampers should fit perfectly tight, work easily and thus afford proper means for controlling the combustion of the fuel.

FUELS

Selection as to type is important. The kind of boiler to select should be governed by the particular job in question with due regard to the conditions which will attend its use. Nothing is more important than that the boiler be suited to the fuel to be consumed therein. Boilers are designed for hard coal, soft coal, and liquid fuel. A hard-coal-burning boiler will not always burn soft coal satisfactorily, nor will a soft-coal-burning boiler always

burn hard coal economically. Liquid fuel can be burned in a coal-burning boiler, but not with as high efficiency as will result from consumption in a boiler designed for oil burning. The problem is different. Combustion conditions differ and the boiler in which characteristics of combustion of the different fuels has had consideration during design, will give the best results.

ATTENDANCE

Some coal-fired boilers require more attendance than others. Generally speaking, the most satisfactory service with highest efficiency can be expected when the most attention is given boiler operation. Heating boilers are built primarily for long firing periods—that is, so that relatively little attention is required. On general principles, this is opposed to economy of fuel consumption. It is a problem that confronts and must be determined largely by the man who pays the fuel bill and operates the boiler—as to whether he will give it frequent and careful attention and thus economize on fuel and obtain better combustion, or whether the time consumed is more valuable than the fuel saved.

Dirty fires caused by neglect in shaking, failure to clean regularly, careless attention to the drafts and boiler surfaces improperly cleaned easily may result in a loss of 25% in efficiency of operation.

BREAKDOWNS

A breakdown always is a possibility. In the case of hospitals, schools and similar establishments, consideration to provide reserve units to guard against the possibility of the structure being without heat is advisable. Where such provision is made, it is customary to install two units, each of about two-thirds the required capacity, so that by operating one boiler, the unit will be proportioned more nearly to the average load requirements and if one boiler should fail temporarily, the remaining unit, by overloading, if necessary, could carry the load until repairs are made.

Where boilers are used for power and heating, or where heating demands are rather severe and

continual, it is advisable to provide at least one reserve unit to permit the withdrawing of a unit from service for the purpose of cleaning.

ERECTION

Placing or erecting of the boiler also is a matter of importance. In the case of round or horizontal sectional-boilers, skill is required in connecting the sections, for unless the joints are true, there is danger of cracked sections; unless they are tightly cemented, air and gases may short-circuit between sections or excess air may enter at undesirable points. No leakage should occur around the base. When the draft door is closed, no air should be able to pass into the boiler; otherwise, control of the fire is impaired.

COVERING

The application of a good insulating covering, such as asbestos or magnesia, is essential. Reduction of heat emission from the boiler frequently may raise the efficiency appreciably. Although for certain reasons the piping may be left exposed, the boiler should be covered.

LOCATION

It is best to locate the boiler as near as possible to the chimney and to place it so that the smoke-pipe can be installed straight into the chimney, omitting elbows if practical. The student is referred to a preceding lesson covering chimneys and flues.

FITTINGS

Low-pressure steam heating-boilers should have for trimmings, at least, a safety valve, water column, gauge glass, pressure gauge and damper regulator.

A water boiler requires an altitude gauge, a thermometer, and it is advisable to include a damper regulator.

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